AN INVESTIGATION INTO NON-DIRECTED THOUGHT PROCESSES AND THEIR PERTINENCE TO INFORMATION SYSTEMS POSSESSING INTELLIGENCE

by

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TO MY WIFE SELCUK

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CHAPTER I

INTRODUCTION

Purpose and Motivation

Objects, events and phenomena closest to us can sometimes be very elusive to our perception. This study will investigate a phenomenon that apparently has escaped scrutiny, a phenomenon that is with every person throughout his waking hours: thought training, or stream of consciousness, or day dreaming or non-directed thinking. Although the last expression appears in the title, "thought train" will be used in the discussions.

The apparent simplicity of this phenomenon is deceiving. It almost seems like background noise. However, closer scrutiny reveals its complexity and its implications for human intelligence. That thought trains might be very important for mental functions can be inferred from the mind's being indulged in it a substantial fraction of the waking hours. Wastefulness does not characterize the mind. If we accept the information processing theory for the brain, then the importance of non-directed thinking would again emerge [9]. From this point of view "thought training" is a very appropriate terminology for it conveys the nature and function of the phenomenon: linking or associating recollections to "train" thoughts.

It is very surprising that the thought train phenomenon has received very little attention in the literature. In fact, I was unable to discover any contemporary study that directly dealt with it. Its non-directedness may partly be responsible for this; it is hard to associate specific problems with it. Current research both in Psychology and artificial intelligence being <u>problem-oriented</u> would <u>not</u>, therefore, bend to the study of thought train phenomenon.

Currently research has been directed to developing management information systems possessing intelligence. It appeared to me that research efforts were very much problem or task oriented. Non-directed, noise-like processes were not being considered at all. Since non-directed thinking appeared so dominant in the mind and, in my opinion, so important for intelligence I felt investigation of non-directed operations for implementation in the management systems was warranted. The following pages will describe my efforts and their results.

Preview of Chapters

My main research tool will be introspection. If we are willing to accept our perception of the environment as data, then the reports of our mind on its activities should be accepted as data also. At the end of this chapter I will defend introspection more.

Introspection can tell us only the results of mental processes. To determine the underlying mechanisms we should do what we normally do with data: propose hypotheses that "explain" data; then make predictions with the hypotheses, and if the predictions prove reasonable, propound the hypotheses as theory.

Chapter II will provide a set of introspective observations as data to be examined and explained. Investigation of these observations will result in a series of thought train process hypotheses as well as a series of hypotheses about the memory structure that supports non-directed thinking.

Chapter III will examine the process hypotheses and will determine their validity using the results of empirical studies of several psychologists.

In Chapter IV the memory hypotheses will be validated in a roundabout way. Using two sets of empirical studies a general memory model will be evolved. It will be shown that this model includes the memory hypotheses of Chapter II. Then the components of the general model will be critically examined using numerous empirical studies. This chapter will also investigate short-term memory, forgetting and possible bases of consciousness. Finally, using the general memory model, a physiological description of the thought train process will be attempted.

I conducted a series of exercises to provide some insight into two components of the thought train process model: image selection and cues. Chapter V will undertake to analyze

the results and delineate some cue types as well as some of the image selection procedures.

After having developed the model for the thought train process and the memory structure supporting it, I will feel ready to argue in Chapter VI what some of the functions served by non-directed thinking are. Nine possible functions will be identified and discussed. They will be classified into three basic functions: (1) hypothesis generation, (2) memory organization and (3) consciousness creation.

In anticipation of Chapter VIII where it will be argued that both the functions and the memory model implications of thought train process are very pertinent to the design of management information system, in Chapter VII the present day computation technology will be reviewed. It will be claimed that the really powerful schemes are not receiving the attention they should.

In the same chapter the major weaknesses of existing computational designs will be examined. I will propose a new design that will overcome these weaknesses. I will also claim that this new design explains an apparent inconsistency in the memory model of Chapter IV and that it (the design) may well be the basis of brain organization. The design is based on logic and memory possessing unit having one-way communication channels (like the neuron). It provides for exhaustive as well as directed search without having to identify or address or label the modules. All intermodule operations are solely based on data content.

<u>Chapter VIII</u> will first examine the nature of the firm and its information system. It will be demonstrated that the human substructure contains parallels to the procedures and purposes of the thought train process as well as to the memory structure. I will argue that the manager faces ever increasing complexity both of the <u>intensive</u> kind where data domain is small but relationships are involved, and the <u>extensive</u> kind where data domain is large but relationships are simple. While the human substructure of the information system appears to be balking in the face of extensive complexity because of (1) limited input capacity, (2) ability to manipulate only a small data base with respect to a given task and (3) lack of precision in processing and output, the machine substructure appears well suited to <u>extensive</u> complexity. It will therefore be argued that the machine can be a very useful extension of man if it could be equipped with <u>low</u> level of intelligence so that it can reduce extensive complexity to intensive whereupon the humans can take over. For this to be possible, compatability between the two substructures must be maintained. Hence the basic problem of designing <u>integrated</u> information systems will be viewed as imparting intelligence to the machine while maintaining compatability with humans.

Next, the structural and procedural requirements for "enough" intelligence and compatability will be analyzed.

It will be argued that the structural requirements are those that can be satisfied by systems designed according to the memory structure in Chapter IV by incorporating the scheme of Chapter VII. Procedural requirements will be shown to be derived from goals or functions exactly analogous to the ones purportedly served by non-directed thinking processes.

I will conclude, therefore, that in designing intelligence possessing management information systems the memory model developed in this thesis should be the basis of system structure; and the non-directed processes as described herein should be the basis of system procedures. This strategy will, I believe, bring us very close to solving the problem of <u>imparting enough intelligence to machine substructure so that it becomes a compatible extension of man's mental capability</u>.

<u>In Defense of Introspection</u>

Introspection must have been a major method of understanding ourselves and our relations to the world about us ever since man acquired consciousness. Psychology, especially before Watsonian behaviorism, stemmed from introspective observations and in fact all that the psychologists were interested in was what went on in people's heads [20]. The early champions of introspectionism included William James and Titchener [20]. The psychology of mental content and with it introspectionism collapses early this century

under the impact of two blows [20 p.588] . First, introspective data did not seem to lead anywhere. The second blow came from the behaviorists who argued that conscious content could not be the basis of a scientific discipline whereas behavior could. According to McClelland this fit in the traditional American pragmatic bias in favor of action rather than thought and feelings generally considered to be old-fashioned European concepts. It seems that even personality and social psychology which by definition are content-oriented fell victim to this movement. So the behaviorists, their stand being summarizable by S-R (stimulus-response), dominated and to a large extent still do so.

However, the tides appear to be turning. Current investigators of fame more and more are pointing to the importance of introspection. For instance Beth and Piaget state:

> The object of psychology is not pure behavior, disregarding all consciousness, as certain extreme schools of thought would have us believe, but rather 'conduct' which includes consciousness, the latter arising from functional relationships which determine the conditions of conscious awareness. Now, as Claparede has shown, to the extent that consciousness occurs when adaptation fails and leads to new forms of adaptation, a valid kind of introspection exists side by side with tendentious introspection. Consequently the introspections of . . . fertile thinkers, once the respective roles played by involuntary philosophical interpretation and actual conscious awareness have been separated, is of a nature to <u>verify</u> and on many points to <u>complete in a very useful manner</u>, the data obtained by the application of 'objective' methods [5] [underlining is mine.]

Similarly McClelland claims that:

> If psychologists are to re-enter the field of mental content and start classifying it according to categories of genuine theoretical fruitfulness, I fear they will have to return to disciplines they have long neglected. [20]

The same researcher concludes that "because of methodological improvements, we are about to take up some of the problems in mental content. . ." This remark exactly corresponds to my sentiments.

One of the most important developments that is bringing problems of mental content to the forefront is the development of the electronic computer in our decade. The production machines, notably the internal combustion engines, provided models of the physiological basis of man and allowed the testing of these models. Similarly, the computing machines are providing a wealth of models for the mental processes of man and also allowing the testing of models embodying psychological hypotheses. The behaviorists ignored introspective theories because they could not be tested in any meaningful way. However, simulation models implemented on a fast computer can produce a wealth of data that can readily be subjected to scrutiny and also form the basis for selecting fruitful theories. Indeed computer is just the tool that could have kept the introspectionists on their feet and the inquiry into mental content alive.

As Russell puts it, "Psychology now has the opportunity to fill the once empty O for organism of its traditional S-O-R formulation with meaningful interrelations between R and other properties of the organism." [23, p.xi].

CHAPTER II

MACRO-MODEL OF NON-DIRECTED THINKING

A plausible model of the thought train process was developed by interpreting a series of introspective observations. We have to try to infer the steps of the process, because as Piaget also asserts, introspection reveals the results of mental activity but not the mechanisms producing those results. Then, the introspective observations become exactly analogous to experimental data in any science. The common approach is to try to explain data with models or sets of hypotheses. The hypotheses are then used to make predictions. Special experiments check the accuracy of the predictions, and if the hypotheses indeed prove predictive they move into the status of theory. In this chapter only a series of hypotheses together forming a process model will be developed. For expositional purposes, below I am presenting a summary of the observations and the explanations as well as hypotheses they evoke. These are then followed by detailed discussions.

Observations	Hypotheses (implications)
1. One thought unit (image) is considered at a time.	1. An image is an ensemble of interrelated items viewed simultaneously (Relationships are mostly natural i.e. observed)

2. Consecutive images are <u>often</u> linked or associated. The associated sequence is often started by an image arriving from the environment and less often terminated by such an image.	2. a. A <u>cue selection</u> process exists and determines the links. b. An <u>image selection</u> process exists and singles out an image from among cue-activated ones and the one that arrives from the environment. c. Existence of some sort of <u>parallel search</u> is indicated. d. Most of the time, thoughts just do not pop into the mind, but are associatively generated.
3. An image is subjected to various tests and transformations in the conscious mind. Sometimes, as a result, inferences are made, and instructions or questions are recalled and acted upon.	3. a. There exists a set of <u>tests and transformations</u>. b. <u>Goals</u>, when activated, partially guide the thought train by influencing cue and image selection processes.

4. A thought train can be reconstructed with both the images and the links (cues) being identifiable. At the beginning, often an externally originated image is found as the trigger of the associative chain. However, reconstruction becomes difficult after an interval of several minutes.	4. a. A <u>follower</u> (which is very likely the short term memory) records the activities of the conscious mind. b. A <u>dual network input</u> system to process external events is indicated, one network being a <u>sampler</u>, the other an <u>analyzer</u>. c. Either there is a single processing center or diffuse processing elements interact harmoniously.
5. Sometimes the next image is an image that was in the conscious mind only a while ago.	5. The contents of the follower (short term memory) are searched associatively too.
6. While retracing a thought train, the image in the conscious process triggers a new thought train.	6. a. Even a specific task or problem like retracing appears to be subject to branching. b. Tasks or problem oriented thinking can be considered a special case of non-

directed thinking or vice-versa. Tests are more used in the former.

7. When a thought train is interrupted, if the image is important, a <u>feeling</u> remains hanging in the chest. After the interruption the thought train is traced until an image is found which causes the feeling to disappear. That image is often the interrupted one.

7. a. Just as <u>word vocabulary</u> represents events and objects, a <u>feeling</u> vocabulary exists which represents how the words i.e. objects and events are related to the organism. Each word is associated with appropriate feelings. Classical conditioning lends credibility to this hypothesis.

b. In as much as feelings affect various organs, the feeling vocabulary may thus be the coupling between thoughts (mental events) and the body. In this sense, they may be or represent instructions to activate various parts of the body.

c. The feeling symbols associated with thoughts may be very significant in goal activation, cue selection and image selection.

The <u>components</u> of the thought train process model would then be:

1. A <u>memory</u> with some sort of parallel search.
2. A <u>cue selection process</u> which determines the cue to be relayed to the memory. Images containing the cue are activated.
3. An <u>image selection process</u> which determines one image to be placed in the conscious mind, from among the cue-activated images and the images coming from the environment. If the image selected is an externally originated one it becomes the starter of a new thought train.
4. A <u>set of goals</u> which the thought train serves to achieve and which partially influence the thought train process
5. A <u>set of tests and transformations</u> are used to activate the appropriate goal and also help realize the goal.
6. A conscious mind or the conscious processor. Both consciousness and the problem of processor will be discussed in Chapter IV.

7. A <u>follower</u> or short term memory records the activities of the processor. It can be viewed as a scratch pad.

The process then operates in the following way: The active goal influences the selection of a <u>cue</u> from the image in the conscious level processor. The cue is relayed to memory in a parallel fashion. Images in memory are <u>activated</u> if they bear a specified relationship to the cue. Images are also arriving from the environment. An image from among the cue-activated ones and the ones coming from the environment, is selected. Selection process is influenced by the active goal. The image chosen then displaces the one in the conscious-processor. (Notice that the new and the old images are <u>associated</u> through the cue.) The active goal's routines process the image. The results may produce a new cue or activate a new goal and the process continues.

The summary presentations should make the discussions to follow more meaningful to the reader. I shall first present an introspective observation and then provide an analysis. The subtitles indicate the process components revealed by the analysis above.

<u>Definition of an Image</u>

<u>Observation</u>: At any one time the mind seems to consider one thought only.

<u>Discussion</u>: The singularity of thoughts, at least at the conscious level, is perplexing. When there are about

ten billion neurons each of which can be viewed as a processing unit (see Chapter IV), why is the mind conscious of one thought unit at a time?

That the mind has much difficulty seeing or being conscious of two things simultaneously is strikingly illustrated by any of the background--figure pictures. Consider the vase and two people facing each other juxtaposed below.

We know that both the vase and the two profiles are there. Yet we cannot see both pictures simultaneously under normal conditions. However, generalizing from this instance is premature because we have not yet defined what is meant by image. Such a definition is also central to our study because thought train was posited as a series of associated images. Indeed what is an image? What are its salient features that would allow us to distinguish two associated images rather than considering the two as one? Much pondering on the matter has produced the following definition: An image or a thought is a collection of components or symbols which are mentally viewed simulta-

neously. The most salient characteristic of the symbols or components is that they often have natural relationship to each other. Infrequently interrelationships are artivicially imposed.

Stated succinctly, an image is an ensemble of interrelated items viewed simultaneously. Simultaneity or parallel perception is inherent in our nervous system. We have many neurons that carry information about an event. The image emerges when all of the information pieces are assembled in accordance with natural relationships.

Some introspective exercises may bring out the plausibility of the definition of image:

Picture your present bedroom. Become aware of various items in the room i.e. the table, bed, chairs, lamp, books, etc. Notice that you can view all or a set of these components simultaneously. Also notice that each item bears some natural relation to others (mostly spatial relationships e.g. the table is next to the bed, they both exist in your bedroom in this combination). Now try to alter the natural relationship e.g. turn the bed upside down. You will notice that it will take a while before you can view an inverted bed simultaneously with other things around. In fact you might alter the image (e.g. to that of the moving day) so that the inverted bed bears a natural (actual) relationship to the bedroom items. Or, you might oscillate between an image of the inverted bed and the bedroom.

Visualize the following items separately: a joker, rocket, jellyfish, Grand Canyon. Now try to form a single image with them. At first you will find this very difficult. Note the tendency to oscillate among images. Also, note the tendency to find a situation where all items are naturally or actually related. And then note the imposition of artificial relationships so to form an image.

Cue Selection, Image Selection Parallel Search

Observation: Consecutive images in a thought train are often linked or associated--no sudden jumps from one thought to another. The associated sequence is often started and terminated by images arriving from the environment.

Discussion: The observation can be explained by hypothesizing that each image contains the address of another image that has something in common with it. Thus, specifying the address brings the image at that address to mind. Such a hypothesis, however, would predict a lot more repetition of sequences. As it is, hardly any thought train contains the sequence appearing in other thought trains. It also would predict that given an image, a person would be able to branch to only a limited number of images. Actually, a person can form innumerable associations. We could, of course, hypothesize that many addresses are included in one image. Such a scheme would, however, require that all storage elements in the brain be assigned addresses

or location identifiers. Decortication experiments in which one-half of the brain is removed reveal no effects on memory. This of course, weakens the location address hypothesis.

A more plausible hypothesis is that the <u>content</u> of an image <u>is</u> the address for the associated images. That is, using the content it is decided whether another image is an associate or not. This can be obviously carried out by serially comparing the image in the conscious processor with every other image. Given the size of the memory this should be ruled out. Comparison can also be done in a <u>parallel fashion</u>; many images being investigated simultaneously. Such a search procedure would allow the examination of a sizeable portion of the memory in a reasonable amount of time. I therefore, <u>hypothesize</u> that content addressability is achieved,in part, through parallel search. Once the relevant domain has been circumscribed a serial search can take place.

If an image has a very close associate (e.g. table and chair) it would be very inefficient to undertake a full scale parallel search each time the very close associates are to be retrieved. In that case the close associates can be stored physically close together. Then a search only in the immediate vicinity would suffice. The existence of close associates and their very easy retrieval compared to

more remote ones suggests the possibility of such a scheme. I therefore, hypothesize that through time close associates converge in the memory and thus, their retrieval requires only a limited parallel search.

A major issue still remains. The nature of association has to be examined. When one image follows another in a thought train,three modes of association can be discerned which make us feel that the two images are associated: (1) Most commonly both images contain common components, (2) Sometimes both images belong to a common context, (3) At other times one image is the context of the other or in other words,one image contains the other.

Therefore, in order to find an associate, either the entire image can be compared with other images or a <u>component</u> of the image can be compared with other images. Both are possible and very likely both modes are used. Whichever is used,be it the whole image or a component of it, I will call it <u>the cue component</u>. I will call the mode of association, the <u>cue operator</u>. A <u>cue</u>, then, is a cue component plus a cue operator,i.e.,an association mode. Since an image contains many components and three possible association modes exist, there has to be a <u>cue selection process</u> that determines the appropriate combination. Furthermore, it is likely that more than one image in the memory will respond to the cue i.e. be <u>activated by it</u>. Also images are arriving from the environment and compete with cue-activated images.for entering

the conscious processor.* Therefore, there must be an image selection process which determines the most suitable image.

Tests and Transformations; Goals

Observation: A thought train is not a simple chaining of associated images. When an image is in the conscious processor, it is tested in numerous ways and is subjected to various transformations. The reader can visualize something and mentally observe that it can be transformed in many ways. He can also observe how certain properties of the image enter into awareness. This must be the result of tests.

As a result of these tests and transformations sometimes inferences are made, and instructions or questions are recalled and acted upon.

Discussion: This observation clearly brings out the active nature of the thought train process. Apparently it serves some very definite functions or goals. The transformations and tests very likely serve two purposes: (1) to activate one of the goals, (2) to help achieve the goal. I hypothesize the existence of several goals served by the thought train process, the existence of tests and transforma-

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*There must be this competition as otherwise we would not have a series of associated images interrupted by an external image. Either cue-activated images or external images would dominate.

tion for activating goals and routines consisting of sequences of tests and transformations that the activated goal utilizes. In Chapter V, I will provide further introspective observations and will infer some of the goals as well as their possible routines.

The Follower (short-term memory); Dual-Network Input; Processing Center

Observation: It is possible to retrace a thought train although doing this successfully requires some self training. Often I start with the last image and working backwards, identify the images and the links or cue components that caused the associations. At the beginning of a thought train I often find an external stimulus as the trigger.

Discussion: Apparently the activities of the conscious mind are recorded most likely in the short term memory since unless retracing is done immediately after about fifteen to thirty minutes it is just impossible to retrace a thought train. The locus of this recordation will be referred to as the follower. This component, which is a hypothetical construct, must be recording not only the images in a thought train, but also the cues as both are identifiable. It is possible that the follower may be trained to store more of the processing steps.

That often one finds an external stimulus as the trigger of a thought train points out that ideas or thoughts

(at least most of the time) do not pop into the mind but are generated associatively. The externally originating image which is the trigger for one thought train obviously is the <u>terminator</u> of another. External images must then be competing with the internally generated ones. Only when the priorities of the former exceed those of the latter do the former gain admittance to the conscious processor. Until then we are marginally aware of events in the environment. Once we become conscious of an event our attention is trained on it and we collect a wealth of data on it. This suggests the possible existence of two input networks. One <u>samples</u> the environment. The resulting images are used in the <u>image selection process</u>. If a component of a sample enters the conscious processor a second network, the analyzer, is activated and focused on the event. The result is dynamic focusing. Very likely this dynamism fosters efficient allocation of attention between external events and internal processing.

An analog of this system is the man-radar system equipped with a telescope. The radar samples the environment. The man processes the samples and if an item proves of interest the man directs the telescope to it.

I hypothesize that we do have a dual network input system and that it is the images coming through the sampler that are processed by the image selection process.

The Follower is Associatively Searched

Observation: When an association is made, I realize that I had made a similar association only a short while ago. Sometimes I identify a new image in a thought train as one I had encountered shortly before.

Discussion: The follower which is either the short term memory or some domain of it must be being searched in some parallel fashion. Otherwise realizing that I had encountered an image a short time ago would not be possible. The previous thought trains are treated just like stored images in the short or long term memory.

Directed Thinking--a Special Case of Thought Train Process

Observation: While trying to retrace a thought train on many occasions I would delve into a new thought train with the thought train image last identified as the trigger.

Discussion: Retracing a thought train is a specific task the mind undertakes. Yet even in the execution of this task branching occurs and one has to make an effort to abandon the branches and come back to the main task. Of course, this is typical of all types of task or problem oriented thinking. Rarely can a person keep to the problem without branching into a tangentially related thought. At all levels of thinking the mind seems very reluctant to keep to a single line of thinking; instead forays into adjacent areas are constantly taken. Consequently it would be plausible

to dub thought train as a special case of thinking, a case where directive forces are weaker; or depending on one's position on the issue to dub thinking as a special case of thought train. At any rate non-directed thinking captures the essence of the issue.

Feeling Vocabulary

Observation: When a thought train is interrupted when the thought was important a reminder is set up; a feeling (of comfort if the image was pleasant, of uneasiness if unpleasant) remains hanging in the chest.* Once the interruption is over any one image that was in the thought train is remembered (often via cues from the environment) and the thought train is rerun until the final image is reached at which point the feeling disappears.

Discussion: It is common experience that thoughts produce certain feelings--of distress, happiness, anger, joy, accomplishment, anxiety, etc. Feelings probably indicate and derive from, how the thought (i.e. what the symbols in the thought represent), relates to the organism. Just as there is a vocabulary of words that the organism has developed to represent events and objects there conceivably might be a vocabulary of feelings that show how the events are

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*Why feelings often have something to do with the chest is a curious phenomenon.

related to the organism. However, feelings are different from words in that they activate various parts of the organism, for example the adrenalin gland, heart beat, respiration, and acid secretion in the stomach. Indeed feelings may be just those instructions that couple the mind to the body.

Classical conditioning lends credibility to this hypothesis. A subject is given a word which is already associated with feelings such as chocolate. The word causes increased salivation. Suppose the word is presented within a circle. After so many presentations, showing only the circle causes increased salivation. Even the word circle causes increased salivation. So the word circle must have been paired in the memory with whatever symbol that represents the feelings associated with chocolate.

The feelings associated with images very likely play a major role in the activation of various thought train goals as well as in cue and image selection--possibly through helping to determine priorities. In turn, a goal of thought train may be to attribute appropriate feelings to images passing through the conscious mind and also to modify existing feeling codings.

This concludes the analysis of introspective observations. Discussions have resulted in a series of hypotheses about the thought train process. They have also led to

hypotheses about the memory. These hypotheses are summarized below:

<u>Process Hypotheses</u>

1. An image is an ensemble of interrelated items viewed simultaneously. The interrelationships are most often natural i.e. in accordance with what we observe in our environment.
2. The consecutive images are generated associatively. Images just do not pop into the mind.
3. Three modes of association exist: (1) the associated images contain common components; (2) they both belong to a common context; and (3) one image is the context of the other, i.e., one image contains the other.
4. To find an associate, either the entire image or a <u>component</u> of it is used. I call this the cue component.
5. The cue component plus a specific association mode (the <u>cue operator</u>) are relayed to memory. If a stored image contains the cue component and satisfies the operator it is activated. That is to say <u>cues</u> (component plus an operator) <u>activate</u> associates.
6. There is a <u>cue selection process</u>.
7. More than one image may be cue-activated. An <u>image selection process</u> determines the image to be placed in conscious mind.

8. Images also arrive from the environment. The image selection process considers them together with cue activated one. If an externally generated image enters the conscious mind it often terminates the thought train and may start a new thought train.

9. The thought train process serves a set of functions or goals. When a goal is <u>activated</u> it influences the thought train process by influencing the cue and image selection processes. Each goal has an associated set of tests and transformation that it utilizes.

10. The activities of the conscious processor are recorded by the <u>follower</u> which is either the short term memory or a part of it. The images in the follower, too, can be activated by cues.

11. Each thought or image contains <u>feeling codings</u>. These represent how the contents of the thought relate to the organism and constitute instructions to appropriate parts of the body.

<u>Memory Hypotheses</u>

1. Retrieval is on the basis of <u>content</u> (i.e. the content is the address), not on the basis of location addresses or identifiers.

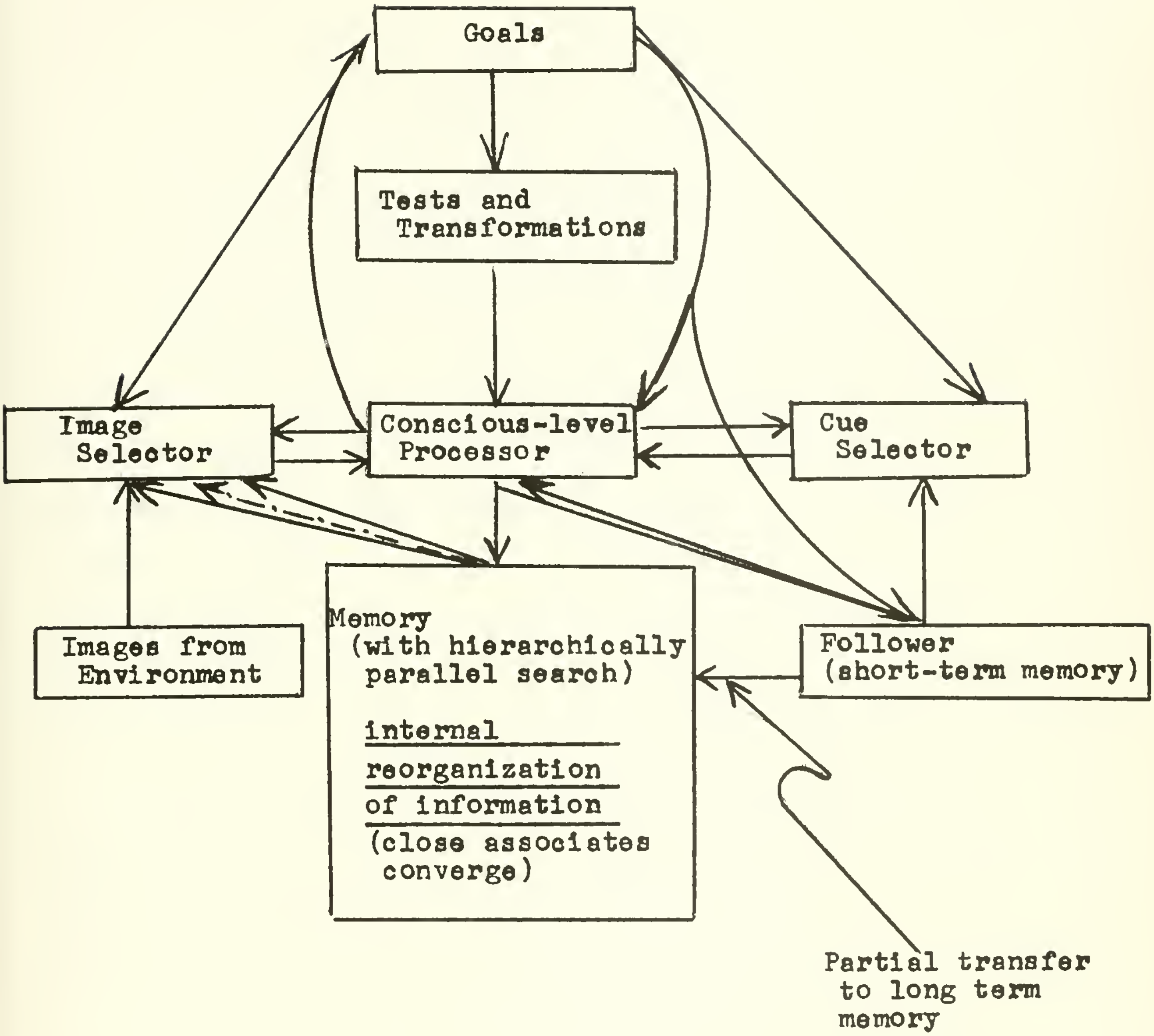
2. Content addressability is in part achieved through parallel search. The memory has capability for both full scale and limited parallel

searches.

3. Close associates through time converge, that is, they are stored closer and closer together.
4. Two networks exist for input, one for sampling the environment, the other for analyzing an event in the environment.
5. There is a processor which is either localized or is diffuse but its constituent components act harmoniously.

A thought train process model based on these hypotheses appears in Figure 1.

The next chapter will try to demonstrate the validity of the more important of the process hypotheses. Chapter IV will examine the memory hypotheses and in so doing will lend more credibility to process hypotheses.



A simpler representation of the model which also describes the gross sequence of events is given below:

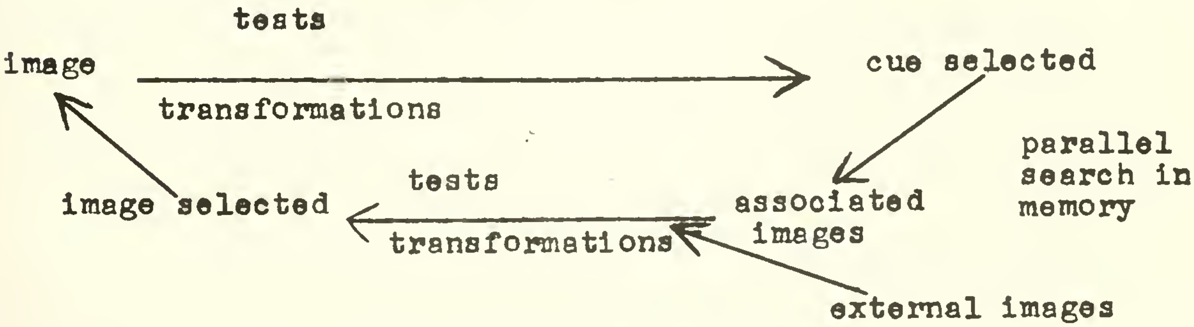


Figure 1.--The Thought Train Process Model

CHAPTER III

VALIDITY OF THE HYPOTHESES ON THE THOUGHT TRAIN PROCESS

The basic hypothesis of thought train process model is that either <u>all</u> or some <u>component</u> of the image in the conscious mind <u>activates</u> images in the memory i.e. the <u>cue-activation-of-images hypothesis</u>. If it can be demonstrated that contents of the conscious mind indeed, activate <u>associates</u>, then image selection process would also be demonstrated since one of the activated images must be selected.

Another basic hypothesis is that in the image selection process the cue-activated images as well as the images coming from the environment are considered. This also needs demonstration.

The cue selection hypothesis states that either the entire image or a portion of it is used to activate associated images. That a portion of an image can be used as the cue is very hard to demonstrate experimentally, since the same results can be obtained by postulating that the entire image is used. I will, therefore, rest my case on a set of heuristic arguments.

The strong sequential associativeness in a thought train needs no demonstration. We all experience that.

However, we have to find out if this is because of system characteristics or because of utility reasons. To resolve this both experimental data and arguments showing usefulness of sequential associativeness are needed.

Validity of Cue-Activation-of-Images Hypothesis

The enormous difficulties involved in experimentally showing the validity of such a hypothesis is obvious. It deals with preconscious events which just are not accessible to our introspection. Fortunately, two series of experiments, one by Schwartz and Rouse and the other by Luria and Vinogradova, bear heavily on activation of associations. Their results tend to confirm the hypothesis advanced here.

Schwartz and Rouse Experiments

The Basic Approach

The main hypotheses behind the Schwartz and Rouse experiments are:*

1. A thought in the awareness [consciousness] activates or primes a constellation of thoughts [images] to which it is linked.
2. The primed constellation is usually preconscious. [that is, activated images in the memory are not accessible to conscious processor.]
3. Associations from this halo may intrude into awareness if they represent some special interest or intention. [That is, there is an image selection process which chooses one of the associates and lets it emerge into consciousness. Goals or intentions influence the image selection process.] [27]

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*The underlining is mine. In the brackets, I have indicated how their terms and ideas correspond to our terminology and hypotheses.

In other words, they also claim cue-activation of images and the existence of image selection. Therefore, validating their hypotheses would validate ours.

They state that although associative activation of thought sequences is well-known and demonstrated by their experiments, the nature of the process still remains to be specified. However, our investigation has produced some insight into the "nature of the process" and has in fact, culminated in operational models of both the memory and of the associative thought processes.

Their experimental design rests on showing <u>associative response tendencies</u>. When a person is presented with a stimulus and later asked to reproduce it, he often comes up with the <u>correct response</u>. This is a well-known fact. For instance, recall tests are based on this: A subject is given a list of e.g. ten words. Five minutes later he is asked to reproduce the list. What is <u>not</u> known however, is that associative response tendencies may also persist into recall or recognition tests. Such persistence would be predicted from the hypothesis that a stimulus activates not only the correct response, but also its associates.

In a traditional recognition form a subject is presented with a set of stimulus words (stimulus list). Some time later a list of words is given to him (recognition form). The list <u>includes</u> the set of stimulus words. The subject is then asked to <u>identify</u> the stimulus words. The

ratio of correct identifications to the number of stimulus words represents the degree of retention. This statistic is the "useful" one. The rest of the data is thrown away. Example:

Stimulus list

house

tree

Recognition form (administered after stimulus list is presented)

car tree street

house river hut

The encircled words represent the responses given when the recognition form was administered a time interval later. The subject recognized only one stimulus word--tree. So his retention is fifty per cent.

Schwartz and Rouse very keenly perceive that the "noise" portion i.e. data thrown away may contain the information to verify their hypotheses. Schwartz and Rouse propose to analyze the nature of wrong responses i.e. those words on the recognition form that the subjects incorrectly thought to be the stimulus words.

In particular in view of their hypotheses they predict that the wrong choices would tend to be the close or frequent associates of the stimulus word.

In a series of experiments which include many variants of the basic design idea, they verify their pre-

dictions and hence validating the hypotheses. They then conclude that:

1. When a word is heard or seen or presumably enters into consciousness, its associates are activated. (This, they call, associative priming.)
2. For associative priming, a purpose to learn the stimulus need not be present.
3. Association strengths are different.
4. Convergent priming only mildly changes activation level.
5. The more likeable associates are activated more.

The nature and extent of these conclusions should be clearer through a more extensive discussion of their experiments.

Discussion of the Experiments

In their basic stimulus list Schwartz and Rouse use thirty-five words from the 100 word Kent-Rosanoff (K-R) list. These 100 words were given to 1008 University of Minnesota students by Russell and Jenkins. The students were asked to provide one associate for each word. From the responses, for each word the most frequently mentioned associate was found for each word as well as the second most frequent etc.

Therefore, Schwartz and Rouse knew before administering the experiments, the associates and their

frequency ranking, for each stimulus word. Their recognition form is based on this. It contains thirty-five lines, five words to a line.

In the first experiment the five words in each line were: one of the _stimulus_ words, its _most frequent_ associate, two intermediary associates, and the _least_ frequent associate. For example one line was:

cottage (stimulus), house (1st associate), cabin (3rd), beach (4th), home (2nd).

The advantage of a recognition form of this kind is that subjects must rely on the form since they cannot search their memory for all the words in the thirty-five word stimulus list. Also, incorrect associative responses are as valuable to the subjects as the correct responses, since they appear on the recognition form.

The subjects were first given the stimulus list and an interval later the thirty-five line, five-word-to-a-line recognition form. They were asked to identify the stimulus words.

The researchers argued that if the associative priming assumption is correct, that is to say, if a word presented to a subject activities its associates and if these activated response persist for a while, then the _errors_ in the recognition form should be related to the associative frequency as determined in the Minnesota tests. An _error_ is identifying

an associate as the stimulus e.g. identifying "hut" instead of "house" in the example given earlier.

As predicted, when errors were made, frequent associates were chosen more often than infrequent associates. The results were significant at .05 level.

It may be argued that frequent associates are chosen because they are often very familiar words. So, when the subject can not remember the stimulus, he simply selects the most familiar word on the line. To see if this were the case the researchers first "fooled" the subjects. A new group of participants were told that thirty-five words would be flashed on a screen at speeds below the perception level and that they would then be tested to see if they would recognize the stimulus words in a recognition form with thirty-five lines and five words to a line. The recognition form was the same as in the first experiment. Only, non-sense syllables were projected at way below perception level. Even these projections were blurred. So in reality the subjects were not given any stimulus words.

The skeptic would predict that the subjects would choose the frequent associates since these presumably are the more familiar ones. Strangely, infrequent associates were chosen more often than the frequent ones. These results demonstrate that the choice of frequent associates in the

recognition test depends upon prior presentation of the stimulus words and is not determined or only weakly influenced by such properties as the familiarity of the associates.

The skeptic may further argue that the results are obtained because the stimulus words appear on the recognition form and therefore help the subject form the associative cluster i.e. cue-activation occurs during the recognition test and not when stimuli are presented.

If this is true then of course, when the stimulus words are left out of the recognition test, the word choices should be random or at best favor the least frequent words. In a series of experiments addressed to this problem, a new group of subjects heard the thirty-five stimulus words, and then were given recognition forms where each line contained <u>not</u> the stimulus <u>but its associates</u> only. <u>Frequent associates were again chosen more often</u>. This finding supports the hypothesis that associative response tendencies are <u>activated during acquisition of the stimulus</u>.

In all the experiments so far the subjects were told that the task was one of recall and recognition. So they were <u>set</u> to learn the stimuli. Can it be that associates are activated even without the presence of an intentional set to learn? To test this possibility another group of subjects were given the thirty-five stimulus words and were asked to rate these words as to their likeability--an incidental learning task. Then the recognition form was

administered. Even though fewer errors were made, among the errors again there were <u>more</u> of the <u>frequent</u> associates. So it appears that the associates of a stimulus are activated whether with or without instructions to learn. <u>Therefore, every encounter with a stimulus may be a potential source of associative priming</u>.

It is really <u>remarkable</u> that primed associative response tendencies can persist into recognition testing. Each stimulus word has its own associative realm, of which only four items are presented on the recognition form. The subjects have no way of knowing in advance that associates will appear on the test form, let alone what the specific associates will be. If the associates appearing on the test form are primed during acquisition, then many associates <u>not appearing on the test form must have also been primed</u>. One immediately wonders if several stimuli share an associate, that is if several stimulus words prime the same associate (convergent priming), will that associate persist into testing phase? Is this convergent priming correlated positively with choice of words? Experiments designed for this purpose indicate a very <u>weak</u> correlation. If the result is indeed valid, then one interpretation that comes to mind is that the source of activation is somehow identified by the memory unit. Such an interpretation which really needs more conclusive results, has important implications for the memory model to be discussed in the next

chapter as well as for the discussions in Chapter VII .

While convergent priming does not facilitate better retention of activated associates, familiarity and likeability of the associate does, according to the results of an experiment which is an extension of the previous Schwartz and Rouse experiments.

Although no satisfactory experimental evidence is present, on the basis of results they obtained and on the basis of their personal convictions Schwartz and Rouse conclude that a hierarchy of stimulus, associative, cognitive and motivational structures i.e. sets can be primed or activated.

Implications of Schwartz and Rouse Experiments

These carefully constructed series of forty experiments only some of which were described here, confirm the process hypothesis that either all or a portion of the image in the conscious processor activate associated images stored in the memory. The existence of an image selection process follows from this.

Since many associates are activated and only one emerges to consciousness, there must be a selection process.

Their conclusion about the activation of a hierarchy of structures or sets corroborates the process hypothesis that contents of the conscious processor activate goals.

That the likeability of an associate facilitates its retention is not surprising. One of the hypotheses I advanced was that words have feeling codings and that these codings play an important role in their selection by the image selection process as well as in their activation goals.

That the convergent priming only mildly changes activation level suggests to me that the storage unit might be keeping track of the source of priming.

The experiments do not shed light on the cue selection process. Nonetheless, they do not rule out the possibility that sometimes a component of a thought acts as the activator.

Although the Schwartz and Rouse findings nicely confirm our hypotheses, caution is necessary in being enthusiastic over this. Their studies contain a major weakness. The associative strength is inferred from associative frequency norms of groups and these norms were developed by other researchers on other groups. Individuals should be expected to vary widely. After all results are only statistically significant. For more confidence, more conclusive evidence is needed. Luria and Vinogradova experiments provide that. [19]

Luria and Vinogradova Experiments

These Russian psychologists remain faithful to the Pavlovian traditions of conditioning. However, their approach

to the association problem is very novel.

They condition subjects to a word. That is a word presented with an unconditioned stimulus like an electric shock. The subject gives a fear response. The procedure is continued until the presentation of the word alone evokes the fear response.

After conditioning is satisfactorily established, the subjects are presented with two sets of words: one set consisting of words that are related in meaning to the conditioned stimulus word (its associates) and the other set containing words that are similar in sound. Surprisingly, the associates evoke the fear response. The similar sounding but non-associated words do not. Therefore, the experimenters conclude that:

> A single verbal stimulus provokes in the subjects, not an isolated, clearly delimited reaction, but a definite system of connections. [19].

Hypothesis: Image Selection Process Considers Images Coming From the Environment As Well As Cue Activated Images

I discovered no one experiment that directly verified this hypothesis. Therefore, I resorted to the standard procedure of using it to make predictions and seeing if the predictions are verified by empirical data.

In the brain, at any location, which is away from primary sensory areas, how can processing units differentiate the real images coming from the environment, and the "imaginary" ones arriving from memory? By the time images

arrive in those units they are far from their sources and they are all coded with neuronal discharge patterns. It seems to me that the answer must be sought in the nature of the images.

Environmental images normally contain a wealth of detail compared to images stored in memory. This can be easily demonstrated. Look at a drawing. A little later reproduce it. Your reproduction will contain much less detail than the drawing. Continue making drawings from memory at intervals. After sometime only a bare outline will be accessible to you.

However, amount detail is a relative matter. If the image selection process does consider environmental as well as cue-activated images, such comparisons can easily be made there. That is, that image which contains distinctly more detail than others (and environmental images do) would be revealed to the conscious process as "real ones" i.e. externally originated. Furthermore, if we tamper with the comparison process either by stopping environmental images or by first filtering them to make them lacking in detail, we should expect the inability to tell the real from the imaginary to follow. Fortunately, experiments based on both kinds of tampering have been conducted.

Sensory Deprivation Experiments

In sensory deprivation experiments environmental stimuli are eliminated as much as possible. Such experiments

were performed among others, by Bexton *et al.*, Smith *et al.*, Leiderman *et al*[30,p.170] In Bexton *et al*'s version, subjects were placed in a small room where they lay on a bed; heard nothing but the monotonous buzz of machinery; had translucent goggles over their eyes so that they could see only a blur of light. They wore long cuffs which came down over their hands and prevented them from touching anything. Those who endured the ordeal first slept a lot, then became bored and restless, and could not think in any concentrated fashion about anything. They frequently suffered from visual and auditory *hallucinations*. A hallucination can be viewed as the inability to separate the real from the imaginary. In another series, the subjects were kept in a completely silent room. Once again an increasing disturbance of thought followed. Thoughts "became incoherent and the observers developed erroneous ideas about their own bodies including feeling of unreality and depersonalization." [30,p.170]

Therefore, as predicted by the hypothesis, if the organism is cut-off from environmental images, the mind cannot tell if internal images are internal and in fact mistakes some of them for real (hallucinations). Hence the hypothesis is supported.

Perky's Experiments: Further Tampering with Image Selection Process

The hypothesis that differentiation of the real from the imaginary rests on a comparison in the image selection process would predict that if we change characteristics of

an external object so that its image loses some of the characteristics distinguishing it from the images coming from the memory, the mind would confuse the real with the imaginary. As was stated earlier one such characteristic is the wealth of detail in a real image compared to internal images.

Perky's experiments confirm this [30, p.174]. He showed his subjects colored shapes resembling a banana, an orange, a lemon and a leaf, in very dim light. The subjects were told to look at the screen on which these shapes were projected. They reported the projections as "mental" images and were not conscious that they were seeing them. However, if the subjects were instructed beforehand that they would perceive these objects they did so normally. Notice though, they needed these instructions to separate the real from the imaginary. So it appears that a comparison does take place and that the degree of detail plays a definite role in this.

If the reader has access to a volume-control equipped source of monotonous sound, he can demonstrate this to himself. Slowly start turning up the volume. At one point you will hear the sound but will not know if you are really hearing it or imagining it.

Cue Selection Process

Since both in Schwartz and Rouse experiments and in Luria and Vinogradova experiments single words were used, they do not tell us whether the whole image or a portion of

it are used to activate associates. Since both are possible at this point, empirical resolution of the issue does not seem possible to me.

In non-directed thinking using a component would be more efficient in that it would require less processing time. In general the more of the image is used the less the number of activated cues would be. It is possible that the more <u>directed</u> the thinking process is the more of components are used in a cue. This agrees with our introspective observations that in day-dreaming consecutive images are weakly related (i.e. they have very few components in common) whereas in concentrated, directed thinking, the consecutive images are strongly associated.

So, I would conclude the cue "component" is a function of the active goals that influence the direction of thinking processes. In other words for coherent thinking we require that consecutive images share many things in common. In a fleeting kind of thinking we relax this considerably.

Sequential Associativeness

Schwartz and Rouse's experiments clearly indicate that sequential associativeness is not because of system's structural characteristics. In fact, they demonstrate that images activated by previous cues sometimes creep into consciousness. I, therefore conclude that the serial associativeness we experience in thought trains is attributable to its usefulness in accomplishing various functions served by the non-directed thinking process.

CHAPTER IV

VALIDITY OF THE HYPOTHESES ON THE HUMAN MEMORY

Introduction

Biological memory is still quite ill-understood. Years of research have yielded very meager results. However, our decade will very likely produce significant results because we now know a great deal about information manipulating mechanisms and also because the secrets of one type of memory--the genetic one--have been unraveled very dramatically.

The thought train model was based on cue-activation of images. Put in other terms the human memory is assumed to be content-addressable. The high frequency of cue-activation which is tantamount to semi-exhaustive search, implies the existence of parallel or semi-parallel search structure since the memory is so massive. That feeling codings play a role in activation weakly suggests that logic may be distributed. The image selector presumably selects an image from among the cue-activated ones. This can obviously be done by retrieving the relevant images and then subjecting them to a selection process. However, since we assumed parallelism and distribution of logic the same result can be obtained by forming a network of the image selecting components, memory components containing the cue-activated images and active

selection through interaction and intercommunication. The thought train model therefore, can be construed to be implying an associative memory with distributed logic and with intercommunication among its components. Instead of trying to justify these implications now I will go through sort of a detour. I will consider two series of experiments with seemingly conflicting results and claim that the above memory model will explain the paradox. Only then, will I bring in further experimental evidence to substantiate the memory model.

Lashley vs Babish et al. Experiments: Towards a Memory Model

Lashley spent many years trying to find the localization of the engram of the memory tasks [15]. He grossly failed. Others like Chow, Mishkin, and Pribram tried too, only to face the same discouragement [ ]. Lashley was forced to conclude that the memory task is the result of all or of a major part of the brain operating in resonance and that the components involved cannot be fractionated to any appreciable degree.

During the past few years several researchers including Schmitt had concluded that macromolecules in the neuron in particular RNA* might form the basis of memory [26]. These conclusions were dramatically borne out

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*RNA stands for ribonucleic acid, a protein which is a very close relative of the chromosome protein DNA.

by the still controversial worm experiments started at the University of Michigan [3]. The general reasoning behind these experiments has been that if changes induced during learning persist after practice is over, then the effects of information storage should be apparent when RNA from trained subject is transferred to naive animals; a significant savingsshould occur in the latter's learning of the task concerned. Babish, Jacobson, Bubash and Jacobson have obtained confirmatory results [3]. In one version of their experiments rats were trained for six days to approach a food cup upon an auditory stimulus and then RNA was extracted from their brain tissue. Similar extractions were made from the same brain areas of untrained subjects to serve as a control. Eight hours later injections through the belly were administered to naive animals and tests for performance of the approach response were given at four, six, eight, twenty-two, and twenty-four hours. The researchers report that:

> The untrained rats then manifested a significant tendency (as compared with controls) to approach the food cup when the click (auditory stimulus), unaccompanied by food, was present.[3]

In a more recent experiment the experimenters substantiated that the effects of RNA are specific and concluded that:

> . . . the RNA effect is dependent on the <u>type</u> of training used before RNA extraction. This would seem to exclude most of the unspecific explanations of the effect e.g. that the RNA formed in the animal under training might, in some way or another, act equally stimulating to any other type of training regardless of the special conditions involved.
> [ ]

It is reported in even more recent experiments where extracts of brain taken from trained donors and injected into naive recipients that:

1. Habituation to sound and air puff was transferred with a high degree of probability and the transfer was specific for the given stimulus.
2. Conditioned avoidance and escape training were acquired significantly faster by recipients of brain from similarly trained donors than by those which received untrained brain extracts.
3. The possibility of information transfer was most clearly indicated in experiments in which the recipients were not submitted to any reinforcement. Changes in their behavior could therefore be attributed to the information encoded in the brain material received.
4. The most consistent results were obtained in recipients injected with brain extracts from donors trained to escape shock into the lighted arm of a Y-maze. After injection, the animals showed a significant increase in their runs toward the light
5. The results were also good but less easily reproducible in animals treated with extracts taken from donors trained to escape into the left or right arm of the maze.
6. The chemical properties of the brain material responsible for the successful transfers

indicate that they consist of peptide chains of varying length.

7. The overall probability that the results obtained in these experiments are due to chance is less than .001. [29,p.12]

Of course in interpreting these results caution is necessary. It still is not certain that RNA alone is responsible for memory. However, with the results, also of other less dramatic but more direct experiments* [23] one is forced to conclude that significant portions of memory are to be found at the macromolecular level; that is memory is very specific. Lashley on the other hand had found that even extensive removal of brain tissue did not impair memory and felt memory could not be specific. On the surface the two sets of experimental results appear conflicting. How can the conflict be explained? Let us probe the brain extract transfer experiments. Apparently either RNA or a similar macromolecule is carrying the information about the maze. The molecule is transported to some place in the nervous system either as is or partly decomposed. Where it is finally deposited is anybody's guess. It would be expecting extraordinary faculties of

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*These experiments show that there is a strong correlation between neural excitation and the rate of protein production in the nerve cell as well as in the surrounding glial cells.

the nervous system to assume that the information on the RNA is recognized and the molecule accordingly transported to one of billions of neurons. Indeed to explain the phenomenon we have to postulate some sort of parallel search so that where the RNA will be deposited is irrelevant. When the maze problem arises the foreign RNA will be located through parallel search and decoded. This postulate becomes all the more reasonable if we consider that the maze information is probably carried by many many macromolecules and that during extraction they are thoroughly intermingled; then the only alternative to parallel search becomes the ability to recognize, sort, sequence, and direct foreign RNA's as they pass a locality--a highly unlikely possibility.

The Michigan experiments also show that memory specificity is to be found below the neuron level, that is to say each neuron has a memory of its own which is probably very large since the amount of RNA in it is large. This may make the people who are used to thinking about the brain in terms of binary switches (the neuron being a single switch) uncomfortable. Let us remember, though, that forty-six chromosomes to be found in the nucleus of <u>every</u> cell contain <u>all</u> the information necessary for the construction of the entire organism. That must be a gigantic amount of information considering the complexity of the human body or any organism for that matter. That each cell indeed has all the

information was strikingly illustrated when a healthy carrot was grown from a single cell taken at random from another carrot.

Once we realize that each neuron (and possibly the glial cells surrounding it) harbors a very large memory probably much much larger than any computer core memory it is only reasonable to assume that each neuron contains a good deal of logic and processing capability. This is equivalent to logic being distributed. Experimental results tending to support this hypothesis will be cited later.

The Memory Model

In a way then, each neuron is more like a good sized computer. These computer like neurons are interconnected and signals flow readily among them. In a given task surely not all the neurons are involved but only some. However, the brain extract transfusion experiments indicate that the maze encoded RNA's can be distributed throughout the brain. This would mean that the intercommunicating network of neurons divides itself into networks each being directed towards a particular task. Initial parallel search identifies those neurons containing pertinent data with respect to the memory task at hand. For the networks to function, routing of signals must be possible. In other words, after initial parallel searches, the signals should acquire directionality. Let me formalize the assumptions posited so far and propose the following memory model:

assertion 1: Each unit (neuron or neuron plus the associated glial cells) has its own memory and processing capability which is sophisticated.

assertion 2: Each unit can communicate with the others.

assertion 3: A signal generated by a unit can easily be propogated to entire memory.

assertion 4: Either all or some of the units can control junction (synapses) hence controlling the routing of the signals. This way any of the neurons can be interconnected.

assertion 5: Each unit (neuron) has a <u>very gross</u> model of the memory i.e. knows something about what other neurons contain. This really follows from the first three assertions. If a unit can communicate with and interrogate other units and also be activated by them it is to be expected that it can store the results of the interrogation and the direction of interrogation and hence slowly develop gross models of contents of other units.

assertion 6: When confronted with a task a neuron interprets the task and generates signals describing the task. Those neurons that contain information or instructions pertinent to the task respond. I will call these the <u>activated units</u>. The signal originating neuron and the activated neurons then interconnect and form a processing

ensemble and it is this ensemble that processes the task and it is this ensemble that should be considered the <u>memory unit</u> for that task.

<u>Lashley vs Babish et al: Discrepancy Explained</u>

Now let us return to presumed descrepancy between Lashley experiments and RNA transfusion ones. Lashley was indeed correct (according to the model here) in concluding that memory is not localized i.e. confined in an additive manner to single fixed units like neurons. The <u>memory unit</u> varies on two dimensions: the number of neurons, domains within neurons. It is quite dynamic, and indeed destruction of some arbitrary collection of neurons would not necessarily destroy the memory trace. On the other hand, memory specificity discovered in the Michigan experiments is congruent with model, too, as was pointed out earlier. Since neurons (and maybe the surrounding glial cells) presumably use chiefly RNA for storage of information, the RNA's carrying the maze data can settle in any neuron. When the recipient brain is confronted with the maze problem, intercommunication and interaction among neurons would activate, among others, the neurons containing the donated RNA's and hence the network formed to serve as the memory as well as the processing unit would have access to information coded on the foreign RNA's.

The Problem of Processor Locality

The memory model suggested here also partially solves the problem of the processor locality. In the artificial intelligence language it is fairly common to talk about the "processor" in the mind. In fact earlier I too, used this term freely. However, just like memory localization was not found, researchers have been unable to localize the processor. Within our framework, however, the processor is not expected to be localized. Instead its logic is distributed throughout. This makes control diffuse too. I am not implying that a monitoring structure is impossible. On the contrary, the very formation of a network is a monitoring structure. However, this localization is temporary, is with respect to a specific task and very dynamic.

The Validity of the Memory Hypotheses

I see a twofold task before me now: to bring in experimental data to substantiate the memory model, and if convinced, proceed to describe how thought train can occur within that model. For the purposes of the first part of the task, I will identify the following as the basic hypotheses of the model:

1. The neuron has both memory and logic.
2. Parallel or parallel like search is possible.
3. Intercommunication is possible.
4. Each neuron has a very gross model of the entire memory.

5. Neurons can interact and modify the activity of each other so that a network is formed.

Neuronal Memory and Logic

I will not dwell on memory any more. It was amply discussed earlier in connection with brain tissue transfusion experiments. For the logic properties of the neuron I will rely on the credibility of quotes from Theodore Bullock of the Department of Neurosciences of the University of California [6]. He states:

> There is some compelling evidence that in the axon terminals the spike gives way to graded, local processes and therefore the all-or-none event itself does not go to the very ends of the axons. . . The neuron, we now think, must be conceived of as a constellation of loci, a mosaic of different kinds of membrane within electronic shouting distance of each other, interacting especially in these regions where the activity is not all-or-none.

He goes on to say:

> It seems difficult to think of dendrites in a cell like Purkinje neuron of the cerebellum as carrying impulses. . . . Now we think on the whole dendrites do not support impulses, either toward or away from the cell body, with the exception in some cases near the base of the dendrite for a limited distance. Rather, the vastly ramified dendrite is like an <u>analog computer</u> where graded events are occurring locally here and there, influencing each other as the branches converge. . . . So we think of the dendrites as being the prime integrative structure, most highly developed in the animal species with most complex behavior. [6]

In discussing the temporal pattern of neuronal output, Bullock wonders how the neuron formulates the patterned output and advances two basic possibilities:

> The pattern may be formulated by neural circuitry by some kind of feedback upon the unit that starts it; or the pattern may be independent of feedback, the unit that starts it being capable by itself, of delivering a patterned output. The evidence is still fragmentary but seems to indicate that each of these possibilities occurs. [6,p20]

For delivering a pattern output, logic capability is a requisite.

Parallel-like Search

If there is parallel-like search then an excitation in one part of the brain should cause a correlated excitation in many other parts of the brain. Furthermore given the vastly complex interconnectedness one would expect the presence of other means of intercommunication than neuronal impulses.

That excitation of a specific location causes excitation in many other parts is common knowledge. This very fact is what makes study of brain structure very difficult. It just is not possible to locate well defined paths of transmission. At any rate experiments of inhibition and facilitation of Hernandez-Peon to be further discussed in the next section show that one part of the brain (the reticular formation) can bring about simultaneous modifications (inhibitions or facilitation) of neuronal activities at all levels.

As for the hypothesis that several ways of semi-parallel search exist, there is evidence that it is not groundless. Bullock describes a surprising kind of neuronal interaction in a number of species. It is not known if it

is universal however. In this so called "specific electrotonic interaction" if an electrode is:

> inserted into one cell, in certain places, and connected to a battery so that a current can be passed into the cell, then, amazingly enough, a recording from an electrode in another cell a milimeter or so away shows the presence of a potential proportional to the imposed current in the first cell. [6,p10]

The phenomenon apparently is not due to field effects of currents in a conducting medium. Current is somehow specifically piped from cell to cell and is not synaptic in the usual sense as it is not necessary to initiate an impulse in the first; in fact an impulse started in the first cell has no effect on the recordings from the second cell.

Of course there is also the interactive field effects. In many nerve tissue preparations one can demonstrate a generalized diffuse effect in a whole region as a result of imposed currents in the tissue. "There is at least some evidence that cells do interact by these weak field effects without necessarily involving nerve impulse transmission. [6,p17]

There are also several enzyme systems which allow neurons to modify the fixation, storage, and retrieval in other neurons. Such massive changes brought about by a small set of neurons can be construed as some sort of parallel interaction. The most notable among these enzyme systems are acetylcholine (ACh), norepirephrine (NE), and serotonin (S-HT) systems. [23,p221] ACh system seems to

be very important for extinction, this also supporting the hypothesis that extinction is a central process. [23, p22]

Intercommunication is Possible: A Dual Network of Sensory Input is Indicated

Ideas presented under parallel search also pertain to intercommunication. For further verification I will discuss a series of very interesting experiments which show that neurons in one-half of the brain can easily intercommunicate with those in the other.

The brain is really two in one. Each half is capable of managing the whole organism. Normally though the right half monitors the left side of the body and the left half, the right side. The two halves are connected by a thick bundle of nerves, the bundle being called corpus colossum. Until recently it was thought that this cable served no other function than spreading epilepsy. So at one time in epileptic patients it was cut with no appreciable effects on mental functions. However, a series of experiments at California Institute of Technology demonstrated that the cable provides for communication between the two halves. For example, if the right hand is trained for a task in split-brain animals (i.e. animals with corpus colossum cut) provided the eyes have not observed the task, there is no transfer to the left hand. One wonders whether in normal animals transfers occur immediately after a task has been learned by one side of the body or when the other

side is faced with the same task. In cats, after the right hand had learned a task, if the corpus colossum was cut, the left hand was found to be proficient in the task. In monkeys, on the other hand, no such transfer was observed. Humans whose corpus colussi were cut for one reason or another exhibit the same behavior. For instance, some of these were found unable to salute with their left hands (Saluting is often a right-handed job.) What some did was to salute with the right hand and thereupon observing how it is done do it with the left hand--a transfer through an external loop of hand to eye. What these show, of course, is that when a member of our body learns a task, the information on the task is stored in that half of the brain which controls it until the member on the opposite side needs it. At this time a transfer takes place. This can only be so if the neurons on one side can readily communicate with the others on the other side and if they can do that surely they can communicate with even closer ones.

Of course such intercommunication can take place by the spread of a signal to all quarters of the brain or by channeling signals to appropriate units. Experiments cited earlier showed that the first mode is surely possible, but it definitely would be inefficient after the first pass after which neurons with appropriate information respond. However, for channeled or directed intercommunication many channels must be cut off. Inhibition at synapses is a well known fact.

Research by Hernandez-Peon [12] as well as others have shown how extensive the mutual inhibitory and facilitory effects are. He states: "There is a great deal of experimental evidence showing that the midbrain reticular formation exerts both inhibitory and facilitory influences at all levels of the specific sensory pathways"and in another place:

> In brief, during attention inhibitory and facilatory influences act at all levels of the central nervous system and require the activity of a central station in the rostral brain stem. This station receives information of all sensory modalities and sends efferent impulses to sensory and motor pathways as well as to the neural systems involved in memory, emotions, and motivations. In turn, the central station controlling general excitability can be influenced by the neocortex, palecortex, or archicortex. [12, p 140]

If the neuron harbors logic and memory it should also be able to direct signals in its fibers without relying on other neurons for this. Bullock describes a "relatively new discovery of inhibition that is currently catching attention" which is called "presynaptic inhibition". [6, p.15] Apparently, at least in certain cases, specific fibers cause an inhibition or facilitation of the presynaptic event just before it reaches the synapse. "This principle enormously expands the range and flexibility of integrative possibilities at the unit level". [6, p.10]

In Chapter II I had hypothesized that a dual network sensory input system exists. One of them, the sampler, relays a shallow but inclusive picture of the environment. This is analyzed, the important events are identified and

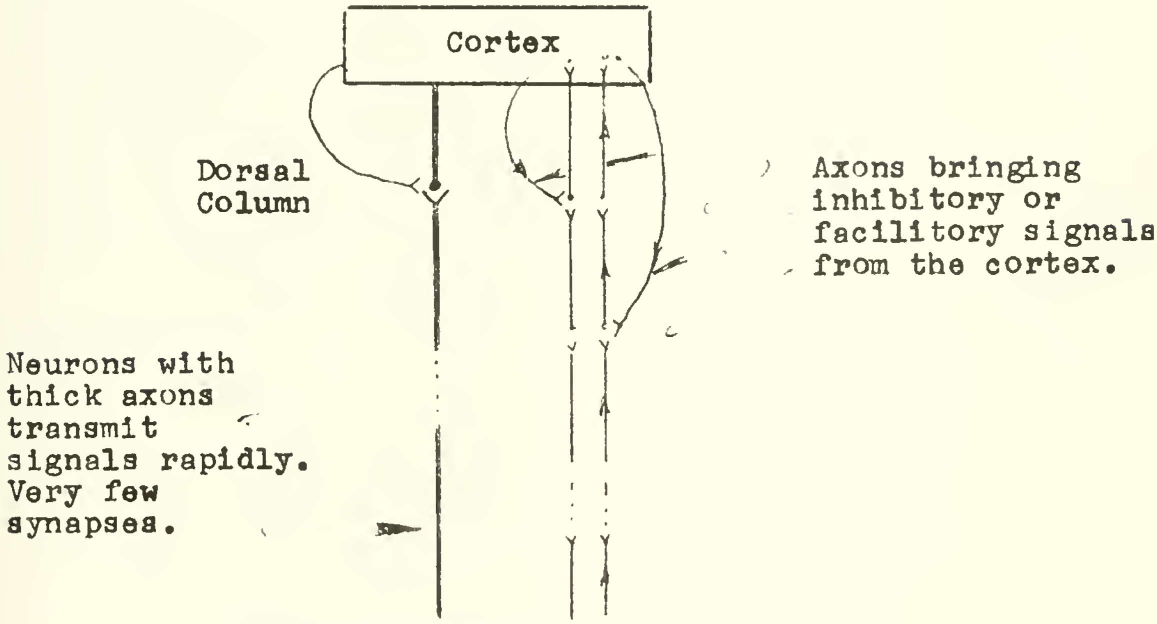
then the analyzer is trained on them. The discussions in the previous paragraphs support this hypothesis. The reticular formation appears to have the capability to bring about modifications at all levels, of the sensory paths.

More direct evidence exists. They come from two experiments. One can be performed by the reader as follows: Find a subject. Ask him to scan a wall from one end to the other. You will notice that the eyeball movement is very jerky. Eyes jump from point to point. Inform him of this. He still will not be able to make a smooth sweep. It is as if when an event does not exist, the eyes sample the environment via the jerky movements. Now provide the event. Hold a finger in front of him and ask him to focus on it and follow it as you make a wide sweep. You will notice that his eye movements are perfectly smooth. It is as if a second input network has been actuated.

The second one can again be performed by the reader. Find a dog. In its vicinity all of a sudden clap your hands. You will catch all of dog's attention. Continue clapping at regular intervals. Soon the dog will ignore you. Now slightly alter the frequency or the vigor of your clap and the dog is with you again, with eyes and ears on you. The changes in frequency and in loudness are all relative things requiring comparison with previous frequency and loudness. So the dog must have been listening to you all along but only marginally i.e. sampling your activities. Any change turns the analyzer on you. This experiment is called

<u>habituation experiment</u>.

On the basis of habituation and the existence of thick axoned neurons as well as <u>descending</u> pathways Melzack [21] has proposed the following model. The dorsal column corresponds to the sampler, the thin axon neurons to the sampler.



Each Neuron Has a Gross Model of the Memory or of Some Portion of It

Here I can only provide heuristic arguments. No experiment, to my knowledge, has either dealt with this hypothesis or produced results directly bearing on it. However, as was shown above each neuron seems capable of initiating both parallel and directed search and communication and is itself subject to these. Given also that each neuron is more like logic memory unit of respectable size then it is only to be expected that it develop a gross model of the memory or at least of the portion with which it often

interacts. Otherwise the ease with which transfer from one-half of the brain to the other half would be hard to explain. So would the massive inhibitory and facilitory action of the reticular formation. Such a hypothesis would also explain the lack of any perceptible change in mental output when large amounts of brain matter are removed. In as much as remaining neurons have at least fragmentary information on what the neurons removed contained and what they did, they can through time take over and perform the functions of the destroyed neurons, too. If such a hypothesis seems too far fetched it should be remembered that each cell within its forty-six chromosomes harbors an informational model for the entire organism.

Neurons Can Interact and Modify Each Other so that A Network is Formed

The facilitory and inhibitory influences of the reticular formation and of neocortex, palecortex or archicortex on the reticular formation is tantemount to dynamic network formation. Reflex loops of all kinds also demonstrate the network formation capability of neurons. In reflex action, apparently neurons at the spinal cord level decide that the situation is so urgent that consulting with upper levels is not warranted so they hook up among themselves and with motor neurons causing an immediate response to the stimulus. That it is really so and not a predetermined

fixed loop action is evident from the upper levels' ability to override the reflex response. The reader can easily demonstrate this to himself. Whenever a stimulus evokes a reflex action in him (e.g. a contact with a hot surface) he can return to the stimulus source and subject himself to the stimulus. If he concentrates enough, no reflex will ensue. Presumably reticular formation has brought about a different hook-up of neurons.

The transfers between half brains also attests to network formation. When the untrained half brain encounters a task, appropriate search locates the knowledgeable neurons in the trained half. A network is formed so that information is transferred to the untrained neurons.

If network formation is a reality, given the observed efficiency of the brain one would expect that repeated usage of certain networks would result in structural changes so that the connectivity of neurons in the network is altered; this makes the formation of that network much easier.

Research by Bennett _et al._ [4], Krech _et al._ [14] and Diamond _et al._ [8] _tend_ to confirm this. Their results are not conclusive but show that highly consistent differences in the weight of the cerebral cortex exist between litter-mate rats exposed to their standard conditions as compared to restricted experience. Adult animals exhibited similar changes. Results are even more

strengthened in view of Levi-Montalcini experiments which demonstrated the presence of growth-promoting substances and neural growth factors which were highly specific for the nerve tissue [18]. Apparently the neuron can alter its connectivity to an extent.

Short Term Memory

So far, I have not discussed the short term memory. Although the memory model postulated in this chapter made no mention of it, the thought train model posited that there is a distinction between the short term memory and the long term one. The former is like a scratch pad, its more important contents in time, being consolidated in the long term memory. The follower which records the activities of the conscious processor was viewed as a short term memory. Experiments performed on goldfish by Agranoff [1] support the existence of short term memory as well as the protein basis of long term memory.

A large number of goldfish (Carassius Auratus) were trained to perform a simple task and at various times before, during, and after the training a substance, puromycin, that interferes with the synthesis of protein, was injected into the fish's skulls. If puromycin was administered immediately after training, memory of the training was obliterated. If the same amount of the drug was injected an hour after training, on the other hand, memory was unaffected. Injection thirty minutes after training produced an intermediate effect.

Reducing the amount of puromycin caused a smaller loss of memory.

The fish were also injected before training. It was found that they learned the task at a normal rate. When tested three days later, however, they showed a profound loss of memory. Evidently puromycin did not block the short term memory demonstrated during learning but did interfere with the consolidation of the long term memory. It also turned out that consolidation was very slow when the fish were left in the training tanks (a high stimulus environment) rather than being taken to their home tanks.

Apparently short term and long term memories are qualitatively different. It is quite possible that the short term involves reverberating currents, whereas long term is the coding of these currents into more permanent structures like proteins.

Forgetting

The memory model developed so far contains no provision for forgetting, a phenomenon which is as ill understood as the mind itself. If RNA is indeed the carrier of memory, true forgetting in the long term memory should involve either the destruction or decomposition of RNA's or the isolation of the neurons containing them. What forgetting is in the short term memory is harder to speculate on. There again if circulating impulses form the engram, their blockage or dissipation would result in loss of memory. One

would, however, predict eventual loss of all memory traces. This does not agree with our experience--even through the years we maintain something of an original memory trace. Also, such hypotheses do not resolve the selective forgetting issue. Because of its simplicity and mathematical precision I will present here, von Foerster's ideas that he advanced some twenty years ago [31]. His predicted forgetting curve* agreed remarkably well with the empirical one.

One of his basic premises is that "any observed event leaves an impression which can be divided into a lot of elementary impressions." This being justifiable "because the sense organs, too, are divided into a lot of elementary sensory perceptors." [31,p112] Suppose initially N_o impressions were made and assume a decay proportional to the number of existing elementary impressions N i.e.

$$\frac{dN}{dt} = -\lambda N$$

This would mean that at time t, the number of elementary impressions remaining is:

$$N = N_o e^{-\lambda t}$$

This, however, does not agree with empirically determined forgetting curves of non-sense syllables. That

*Forgetting curves are derived by having a subject memorize a list of words or nonsense syllables and then testing him at regular intervals to determine what fraction of the original list he still remembers.

such curves are obtained by administering recognition tests at regular intervals motivated von Foerster to:

> assume that each syllable or part of such a non-sense syllable, whatever we would like to define as the elementary impression--is fixed on a certain carrier, many of which may be in the brain ready to be impregnated by such an elementary impression. . . and [that] such a carrier is not able to carry forever its impregnation but only during certain time and decays after time T to a free carrier. [31, p115]

Periodically, he further assumes, <u>all carriers are scanned</u>* and where an impregnated carrier is found its impregnation is transmitted to a free one. It is easily seen that such a process would keep some items in the memory even if each carrier has only a finite lifetime. Under these circumstances intensity will be proportioned to N, the number of impregnated carriers. Efficiency will be proportional to $N_o - N$, the number of free carriers.

The number of transmissions per unit time can now be defined as:

$$\mu N (N_o - N)$$

where μ contains the efficiency coefficient and the frequency of scanning. The entire process of forgetting and memorizing can now be determined as:

$$\frac{dN}{dt} = -\lambda N + \mu N (N_o - N)$$

or

$$n = \frac{N}{N_o} = \frac{k - \lambda}{k - \lambda e^{-(k - \lambda) t}}$$

---

*Notice that this is tantamount to exhaustive search and would <u>not</u> be feasible without some sort of parallel search.

Von Foerster then computes the constants k, λ from the Ebinghaus forgetting curves, and then plots the previous function along with actual curve. The deviation is around five per cent--a remarkable prediction in view of the very simple assumptions. The two curves are given in Figure 2.

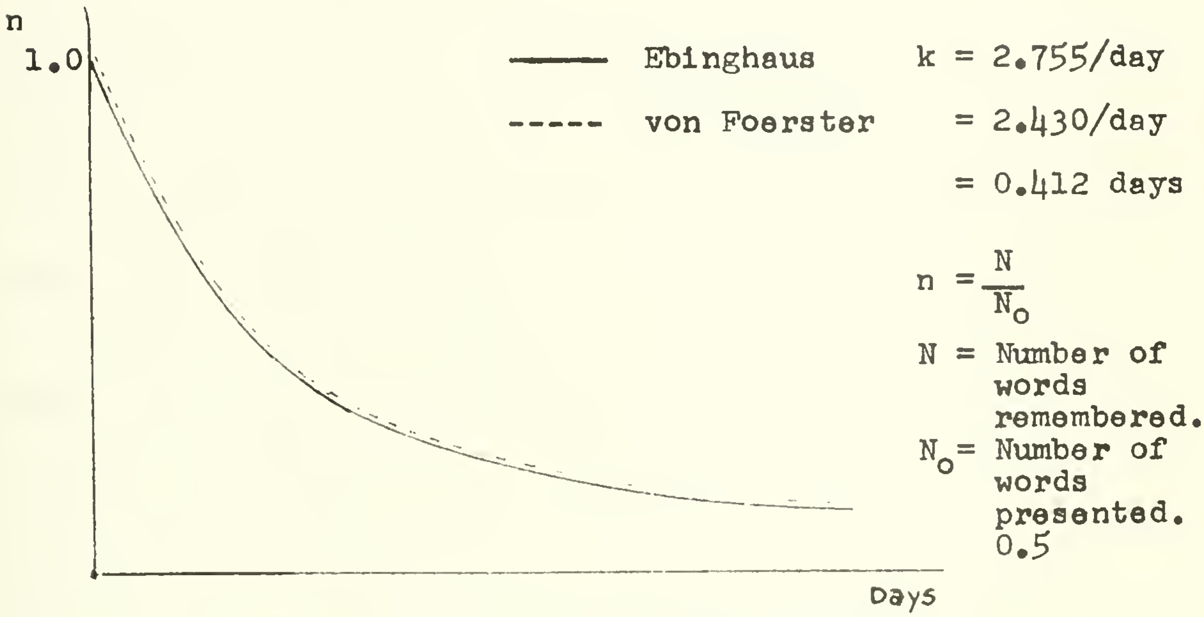


Figure 2.--Ebinghaus and von Foerster Forgetting Curves

von Foerster feels that it is:

> . . . quite reasonable to assume that bits of information which have any relation are also located very close to each other. Before you have the relation you have to go through a hard and painful thinking process to set up the relations for the long-distance transmission one has to carry out. . . . But immediately after this transmission, both items are put together and start with transmissions in their neighborhood producing a slowly growing cloud of connected information. . . . [very likely] we have the same item stored many times in our memory, always with different connections. [31, p191]

The "Quantum Theory of Memory" fits quite well into the discussions here. Firstly it rests on memory specificity. Secondly, it presupposes a periodic scanning of the entire domain pertaining to a memory trace. Given the number of memory traces such a feat would have to rely on some sort of parallel search. Thirdly, he posits a gradual grouping (convergence) of like items and this implies at least very simple distributed logic. Fourthly, the Schwartz and Rouse experiments as well as those of Luria <u>et al</u>. indicate the existence of scanning which "activates" the associated images. Finally, thought train can be easily viewed as a method of <u>internal</u> scanning. It activates associated images which may mean the prolongation of their lives. Also insofar as it is built on an <u>outside originated</u> image (trigger) the thought train couples the "memory reinforcement" to events outside the organism.

It is interesting to note that Henry W. Brosin, a participant in the symposium where von Foerster presented his paper, argued as follows:

> Dr. Lashley's work, with which you are acquainted speaks against brain localization, and more picturesquely, perhaps, also the brain of Pasteur, who unfortunately at the height of his powers suffered a cerebral accident. Upon his death, an autopsy was done and it was discovered he had literally one-half a brain because the other half had atrophied. . . . The evidence that Dr. Lashley has worked over so extremely well for the last twenty-five years and the example of Pasteur mitigates against the proposition of finite locale. [31, p191]

Von Foerster left this remark without an answer. Had the research on protein basis of memory been going on then very likely he would have given counter arguments in some ways resembling those I provided earlier on exactly the same point.

If the intent of this study were different, I would have delved into the von Foerster theory much deeper and related it as much as I could to current knowledge of memory. I shall leave this to the interested expert.

The Memory Model and The Thought Train Process

At the beginning of this chapter I had set for myself, a two-fold task: explicating the memory implications of thought train model and then relating the thought train process to the memory model thus arrived at. For my purposes, I consider the first half of the task finished. I shall now proceed to the second.

In particular, the strong sequentiality and associativeness observed in thought trains must be explained. Closely intertwined are the issues of strengthening of associations, and consciousness.

The Problem of Consciousness

Earlier I had defined consciousness as perception of and access to alternatives of action. I had also indicated that this would require self, environment and interface models. Insofar as the action alternative is what the

organism can do to the environment or to itself, I feel consciousness would entail the inclusion of <u>motor</u> neurons and the neurons containing the appropriate segments of the self, environ, and interface models, in the <u>memory network</u> i.e. the memory unit. I would therefore expect the <u>general locus of consciousness</u> to be in those areas of the brain which have free access to memory and to motor neurons or which intermediate between such neurons. There is one such center: the reticular formation which "does most to integrate the complex of sensory motor and autonomic-nervous signals." [13, p.1] On the basis of his and his colleague's experiments Hernandez-Peon focuses on rostral brain stem where we find the bulk of reticular formation as the locus of attention which is really a manifestation of consciousness. He states:

> In brief, <u>during attention</u> inhibitory and facilitory influences act at all levels of the central nervous system and <u>require the activity</u> of a central station in the rostral brain stem. This station receives information of all sensory modalities and sends efferent impulses to sensory and motor pathways as well as to the neural systems involved in memory emotions, and motivations. In turn, the central station controlling general excitability can be influenced by the neocortex, paleocortex, or archicortex. [12, p.140]

The very process he is describing can be operationally described in terms of dynamic networks as posited in <u>Digression: Kilmer's Model of the Reticular Formation</u>. It is very interesting to note that Kilmer <u>et al</u>., who tried to model the reticular formation, indicate that the "analysis

of its circuit actions heretofore proposed in terms of finite automata or coupled nonlinear oscillators has failed." They, instead, propose " a radical set of nonlinear, probabilistic hybrid computer concepts" and develop a model whose:

> . . . basic structure is that of a string of similar modules, wide but shallow in computation everywhere and connected not merely from module to adjacent module, but by long jumpers between distant modules. [13, p. 1]

Notice that this proposal in essence is very similar to our proposal of distributed logic units with memory and with intercommunication. The latter is fully utilized in their design strategies of:

> . . . modular focusing of input information; modular decoupling under input changes; modular redundancy of potential command (modules having the most information have the most authority); and recruitment and inhibition around reverberatory loops. [13, p. 1]

The reader's attention is particularly drawn to potential redundancy of command. Each unit has apparently as much capacity for dominance. However, actual authority is a function of the greatest amount of information. As will be remembered, I had claimed that when a task confronts the organism, the neurons containing pertinent information hook-up and form the memory as well as the processing unit for that task. In other words, because of their information content these units gain dominance over the others, with respect to the task at hand.

Singularity of Consciousness

After this brief digression to the reticular formation, let me turn to the singularity of consciousness i.e. why, for example, we have one rather than two simultaneous thought trains. Here again, the definition of consciousness posed earlier proves relevant. Accordingly, a conscious activity entails perception of and access to alternatives of action. Were we to become conscious of multiple activities, the motor centers might receive conflicting instructions with resultant confusion and also their capabilities would be divided.

The memory model, therefore, does not rule out multiple consciousness but helps to show it to be inefficient and possibly detrimental to survival. It is not hard to find instances where multiple consciousness might exist. Napoleon is reputed to have had the ability to write two different letters simultaneously, one with each hand. The reader can demonstrate to himself that through some effort he can be conscious of two independent activities like the music on the radio and the ticking of a clock. However, the attention he can devote to each will be noticeably less than the attention he can devote to one of them all by itself. Presumably through self-training, we can unlearn our natural tendency and learn to be conscious of several activities simultaneously.

Associativeness of Images in a Thought Train

The memory and processing unit was described as an interconnected, intercommunicating set of neurons which included motor or reticular units in the case of conscious activities. Insofar as these neurons are content addressable, the next "network" can be formed in one of two ways: either by an impulse emanating from the existing network or by an impulse emanating from the environment. If the former the next network will be related to the present at least through the impulse (cue) sent. If the latter, an entirely new network will be formed and this is exactly analogous to a new thought train being started by an environmental image. However, there is one fundamental issue: at any one time stimuli are being sent to the brain by the current network and henceforth non-activated neurons are being activated. Also, stimuli emanated by the previous networks also activated neurons. Why is it then, that a set of neurons whose activation relate to currently-sent stimulus are selected and not those activated earlier. Within the framework of thought train process the same issue can be stated as follows: if each image can activate images in memory (of Schwartz and Rouse Experiments) why is it that the <u>next</u> image bears a relationship to the current image and not to the previous ones; why is it that the image selector chooses from among those that are activated by the current cue and not those activated by previous ones.

The strong sequential associativeness, however, is not a universal phenomenon. People are able to generate seemingly random sequences. However, studies by Judson, Cofer and Gelfaud show that associative relationships govern the supposed free choice of words[27,p.10]. Presumably the random sequence appears random because we choose from among previously or currently activated images. It seems to me, therefore, that the reasons for strong <u>sequential</u> associativeness in thought trains should be sought among functional rather than structural reasons. Functional reasons will be amply provided in the next chapter.

Thought Train in Terms of the Memory Model

Now thought train can be described in terms of the memory model: (1) An external image activates some neurons associatively i.e. those neurons containing information relating to the image. This is so because memory is content-addressable; (2) the activated neurons connect with the sensory motor centers (or the reticular formation) which brought in the image in the first place; (3) the network thus formed constitutes the memory and processing unit for the image. The image is now in the <u>conscious processor</u>; (4) next, a <u>portion</u> of this conscious experience i.e. a cue is relayed to memory through some sort of parallel search; (5) new neurons are activated and a new net is formed containing some of these newly activated neurons; (6) this

associative process continues until an external image of sufficient priority develops, whereupon its activated neurons hook up with sensorimotor centers and a new thought train proceeds.

An Apparent Inconsistency

The hypotheses that the brain is mostly content-addressable through parallel search and that it is able to form networks where message flow is directed may appear unreconcilable. In fact, for quite a while the inconsistency perplexed me. When a neuron has no location number, how can it connect, through millions of intermediary neurons with an activated neuron whose location is unknown and how can an activated neuron send a message to the activating neuron without knowing anything about its whereabouts and without resorting to a full scale parallel search? It is possible. Chapter VII will undertake to demonstrate that.

Conclusion

Clearly, this is a gross simplification of a very, very complex process. However, I contend that the memory model of thought train process based on numerous empirical studies provides many operational hypotheses that can suggest very pointed and meaningful experiments. I also contend that the model can be very usefully employed in the management information systems context. The final chapter will be directed to that contention. The next chapter will undertake to analyze possible functions of the thought train

process. Such analysis should more clearly demonstrate pertinence of this study to management.

CHAPTER V

INVESTIGATION OF CUES AND OF IMAGE SELECTION PROCESSES

The previous two chapters demonstrated the possible validity of the basic thought train process hypotheses and of the memory hypotheses. The intent of this chapter is to launch an investigation into cue types and the image selection processes. The investigation depends on a series of exercises that were given to fifteen subjects.

In the last two chapters the procedure was to show the validity of certain hypotheses. The approach in the current chapter is distinctly different: it attempts to demonstrate the existence of certain cues and image selection procedures. Providing instances where that which is presumed to exist is realized, is sufficient to show "existence." It has to be this way in our case because the cues as well as image selection procedures can be as many and as detailed as we please, and the exact set of cues and procedures used varies from person to person.

Investigation of Cues

Exercise One: Cue Types*

This exercise was intended to provide some understanding of the nature and kinds of cues. In Part A, the

*The exercises have been placed in the Appendix. If the reader is unclear about the explanations here, he should refer to the Appendix.

subjects were provided with three lists each containing five words which were all nouns selected randomly from a book. The subject was then instructed to:

1. Look at the first word in the list and mentally picture what it designates.
2. Do the same for the next word and so on until the list is exhausted.
3. Return to the first word and write down as clearly as possible what he mentally pictured, and do this for all the words in a list.
4. Repeat steps 1 through 3 for the other two lists.

The results of list 1 were ignored since it was intended as a warm-up trial. The aim of Part A was to commit the subject to a definite image or designate for each test word. In Part B, the last two lists appeared again this time the subject being instructed to:

1. Start with the first word and recall what he had mentally pictured and then picture something else related to it.
2. Record this second image and the relationship between the two images (the cue) i.e. what brought the second image to his mind.

Hence in part B, I obtained the related image as well as the cue and proceeded to generate plausible generalizations.

Expectedly, a wide variety of images and cues were supplied which in turn made analysis somewhat difficult. To see the patterns more readily, the response for each of the ten words were tabulated. Then, the responses to the images as well as to the cues were classified or labeled. Below is an example of this procedure for three of the test words; caricature, people, and diamond.

Test Words		Response	Classification
Caricature	Image 1:	Sunday newspaper comics	general, non-personal
	cue:	Place where I read Sunday comics for years while growing up	frequent context personal experience
	Image 2:	Living room at home	specific, non-person
People	Image 1:	Large crowd of people standing together	non-specific, person
	cue:	A crowd gathered during the intermission of a play seen recently	a specific context, recent; seeking purpose
	Image 2:	Theater	general, non-person
Diamond	Image 1:	Large gem with many facets	general, non-person context
	cue:	Diamonds are for engagement rings	place of use, purpose
	Image 2:	Engagement ring	general, non-person

Such tables were then visually inspected for possible <u>cue types</u>.

In Chapter II a cue was proposed as a component (which can be the whole image) and an operator which specified the association mode. In the same chapter I had proposed <u>three</u> modes of association. Calling the image in the conscious processor the <u>source</u> image and the images that will be searched, the memory images, these three modes would be: (1) source and memory images contain common components, (2) memory image is a component of the source image or vice-versa (this really is a special case of mode one), and (3) both images appear in a third image.

The exercises showed the existence of all three modes. The existence of three more modes was indicated. These six operators, furthermore, appeared to fall into two categories. The first four actuated simple retrieval and have therefore been called <u>linking operators</u> and the cues using them, the <u>linking cues</u>. The last two, on the other hand, brought about changes in the images they activated and therefore have been called <u>modifying operators</u>. Examples below illustrate the linking cues:

<u>Cue type 1</u>: IMAGE + ENLARGE CONTEXT

Example: image 1: Cezanne's painting on a wall

image 2: The whole living room where this picture hangs

Clearly the processor image is a component of the memory image.

<u>Cue type 2</u>: COMPONENT + FIND ANOTHER CONTEXT

Example: image 1: bank statement (in response to interest)

image 2: Philadelphia and a bank around 30th Street

Here both images contain a common component--bank. The new context in this example is a declarative statement. However, it could have been an interrogative as well as an imperative statement.

<u>Cue type 3</u>: COMPONENT + FOCUS. A COMPONENT OF THE IMAGE IS CHOSEN AND THIS IS RECALLED IN GREATER DETAIL.

Example: image 1: A crowd of people in Times Square on New Year's Eve (in response to <u>people</u>)

image 2: The faces of the people in the crowd.

<u>Cue type 4</u>: IMAGE OR COMPONENT + FIND ANOTHER CONTEXT AND CHOOSE A DIFFERENT COMPONENT

Example: image 1: Four sided figure--both the gem and the baseball connotations arise.

image 2: The band of the ring carrying a gem--stone.

These four cues are the ones that were identified also in Chapter III (cue types 1 and 3 were then viewed as one). These cues, as the reader will observe, bring about activation

of existing images only. They are _passive_. Exercise I revealed the existence of _active_ cues, those that bring about modifications in the images they activate. I have called them _generating cues_. One of them appears below as "cue type 5."

Cue type 5: IMAGE OR COMPONENT + MERGE

This entails two operations: activation of a particular image in memory and its merger with the processor image or a component of it. Because the results of _Exercise I_ were only suggestive _Exercise II_ was designed to produce more definitive data on this cue type.

Exercise II:
Merge Operation

In this exercise the same subjects were presented, the ten words in pairs appearing in lists 2 and 3 of exercise one. They were asked first to recall the image generated previously for each word of a pair, then to combine or merge the two mental pictures and finally to record the composite image in sufficient detail. The results very strongly confirmed the applicability of the image definition given earlier.* In most cases the two images were merged into a new image by finding a context in which the two images,

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*An image was desined as a simultaneously viewed ensemble of events or objects bearing a _natural_ relationship to each other.

some of their components or some variant of the images were related in a natural way. By natural, I mean being in conformity with what we observe in the environment. It very definitely appears that in merging two images, say A and B, the subjects scanned their memory to find an image C combining or containing both. Failing that, an image C' containing either A or B and a component of the other was sought. Failing that, an image C'' was <u>created</u> by establishing a <u>natural</u> relationship between A and B. This last case really constitutes another class of generating cues. I have called it <u>predicate transfer</u> and will comment on it very shortly. First, let me give examples for various types of the merge operations.

<u>Image C combines both A and B</u>:

A: Mass of people in the Commons

B: Governor Volpe

C: Volpe speaking to the mass of people

<u>Image C' combines A and a variant or a component of B</u>:

A: Inside a classroom, in Primary School

B: Sunday newspaper comics

C': Students inside the classroom reading comic <u>books</u>.

(When the subject was questioned why she altered the "newspaper comics", she said it was not <u>natural</u> for primary school students to read Sunday paper comics in the class. However, students were allowed to read comic books on some special days).

<u>Image C'' combines variants or components of A and B</u>:

A: Headline for National Observer

B: Diacritical marks in a dictionary

C'': The newspaper (National Observer) with an article on pronunciation

It seems clear that people accummulate a vast number of natural relationships and in constructing an image consisting of several components, appropriate "natural" relationships are retrieved and imparted to those components. I call this predicate transfer, and define predicate as:*

> something that is affirmed or denied of the subject in a proposition in logic. . . . a term designating a property or relation . . . the part of sentence or clause that expresses what is said of the subject and that usually consists of a verb with or without objects, complements, or adverbial modifiers.

The <u>predicate transfer</u> constitutes a new mode of association and it is active in the sense that modifications in the cue component and/or in the activated images take place. A component plus this association mode is then, a new cue type and it is of the "generating" kind i.e.

<u>Cue type 6</u>: IMAGE OR COMPONENT + ADD A SPECIFIED PREDICATE

Such a cue causes the activation of images containing the component and also images containing the predicate. The predicate-containing images are then used as templates for adding the predicate to some subset of the cue component-containing images. Exercise III was designed to reveal this

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*Webster's Collegiate Dictionary.

process more; its structure as well as the results it produced are discussed below.

Exercise III:
Predicate Transfer

Subjects were given a list of words and were asked to form mental pictures corresponding to these words and write down their mental visualizations. The same words were presented again, but this time with a modifier; subjects were instructed to record in detail the image they visualized. The exercise was repeated with two modifiers; subjects recorded the resultant images. Being confronted with an imposed predicate which bore no obviously natural relationship to the image many of the respondents found new images that contained some components of the first image and also the predicate.

To illustrate the point, let me take the two extremes: one in which the modifier has a relatively natural relationship to the image, and one which does not. For the former, consider "picture" and "oblique picture;" and for the latter, "diamond" and "orange diamond." Most of the respondents gave the same answer to oblique picture. Below are some examples:

In response to Picture	In response to Oblique Picture
Picasso's Guernica	The Picasso viewed from my desk
Picture of a white house . . .	Picture viewed from an angle
Framed picture at parent's home	Painting tilted at an angle
Painting my mother did	Painting turned slanted on wall

Responses to diamond and orange diamond varied greatly. The most obvious explanation is that there are very few environmental events that combine diamond and the predicate "orangeness". In other words, the conditions that exist in images containing the predicate orangeness are not easily contained by or readily compatible with the properties of diamond. Below are some examples of the responses:

In response to Diamond	In response to Orange Diamond
Ring	Psychedelic vision
Baseball diamond	An orange with a diamond ring stuck into it
"Lucy in the sky with diamonds" a song by Beatles	A difficult image (a comment)
Large gem with many facets	An orange slightly behind but alongside a diamond
A four-sided figure. Both the gem and the baseball connotations arise.	A man-made diamond modified to give this otherwise impossible color
Wet blue clay--bits of hardness	Orange clay

(This respondent had very little difficulty perhaps because "orange color" is somewhat natural to clay).

The second part of the experiment in which subjects were presented a word with one and then two modifiers

supported the hypothesis even further. For example, in visualizing "orange diamond" subjects had great difficulty. However, once having done that, the second modifier "tiny" presented little problem. This is probably due to the fact that the predicate "tinyness" is <u>natural to many objects and events</u>. Again, let me give some representative examples:

<u>In response to Orange Diamond</u>	<u>In response to Tiny Orange Diamond</u>
Psychedelic vision	Fading psychedelic vision
An orange with a diamond ring stuck into it.	A mandarin orange with a diamond ring stuck into it
An orange slightly behind but alongside a diamond	A small orange slightly behind a diamond
A man-made diamond--modified to give this otherwise impossible color	Industrial quality off-color diamond

Exercise IV: More on Predicate Transfer

This exercise provided more of supportive information on the predicate operator. Sentences were divided into phrases, each phrase including the previous one. Subjects were asked to mentally picture the first phrase

and record what they visualized. They were then presented with the next phrase and asked to visualize and record the next phrase, and so on. The process is identical to what goes on in our mind when we sequentially read a sentence. At each phrase we modify phrases generated previously. Often, though, we are not quite conscious of it. This experiment tries to capture the process in slow motion and I feel that it or its variants can be <u>very</u> useful in understanding not only predicate transfer, but a variety of mental phenomena. One of these phenomena is understanding sequential input (e.g. written material) which amounts to constructing a representative image for the whole idea through creation which amounts to taking an idea and converting it into a sequence of phrases.

To give the reader more of an understanding of this exercise, I shall describe the second trial on it. The sentence used was, "Auto-safety planners are considering more than a dozen novel features that probably will be required equipment on cars." It was divided into phrases as follows:

1. Auto-safety
2. Auto-safety planners
3. Auto-safety planners are considering
4. Auto-safety planners are considering more than a dozen novel features
5. Auto-safety planners are considering more than a dozen novel features that probably will be required equipment

6. Auto-safety planners are considering more than a dozen novel features that probably will be required equipment on cars.

Understandably, subjects found this experiment the hardest of them all. While reading a sentence under normal circumstances the images at the start are often different from the final one. At each step, we try to impart the indicated predicate to the image developed up to that point and at points we simply discard that image and select one to which the predicate is more natural. We are not quite aware of these. The experiment, however, forced the subjects to explicate the intermediary steps. Perhaps this increased the committment to transitionary images and hence decreased the ease of moving to more satisfactory images.

This is of course quite in congruence with the predicate transfer hypothesis posited here. To further explicate the congruence, I will present some typical answers to the first four phrases in Trial Two.

	Auto-safety	Auto-safety planners	Auto-safety planners are considering	Auto-safety planners are considering more than a dozen features
1.	Safety belts	Dr. Something or other with bow tie	Same with furrowed brow	Same with piles of diagrams on desk
2.	Report on seat belts	The Cornell Auto-safety building	Men in the building sitting around a table	These guys with papers on the table

3.	Auto-Safety Posters	Group of businessmen in an office	Group of men talking around a table	One man speaking to the group about a report on required equipment
4.	A suspending seat-belt in a VW	A group of middle aged men around a big table with diagrams	The same group; one drawing a diagram on the board	Blackboard has 13-14 diagrams . . . men ready to vote.

Notice how all the respondents <u>discard</u> the image for "auto-safety" when faced with auto-safety planners. However, images then on <u>are simply modified</u> to reflect the new predicates which, it happens, are <u>natural</u>.

This concludes my discussion of cues. I have proposed to define a cue as a component plus an operator; and have identified two main types of cues: linking (passive) and generating (active). Using examples from the four exercises conducted, I have postulated the existence of four linking type and two generating type cues one of the latter being (component + predicate transfer). Since this cue appeared important, its existence and nature were described at some length.

Undoubtedly many more cues exist. For a more complete understanding of mental processes more of them should be identified. Exercise 4, which was used to some extent for describing predicate transfer cue, if administered on a larger scale, can be especially <u>useful</u> for a more penetrating study of cues.

Image Selection Process

In Chapter II, I posited that a cue activates several images and that images also arrive from the environment. The image selection process singles out one of these images and places it in the processor. There, I also indicated that this "selection process" is a hypothetical construct and that its activities are closely tied to those of the processor. However hypothetical it may be, it is useful to make this construct. Chapter III presented some evidence supporting the activation of multiple images. Evidence was also presented supporting the competition of internally generated images with externally generated ones.

In this section I shall examine the image selection process in some detail. A significant portion of the discussion will simply bring into sharper focus ideas developed in earlier chapters. The new ideas to be introduced will be based on introspective observations. The exercises will be used as before--only to demonstrate the existence of certain rules and not to prove their universal use. The image selection process, I think, is even more subject to variation

from person to person than cue types used.

Images in the domain of the image selection process fall into three categories: (1) those activated by the cue and hence related to the image presently in the processor i.e. the associates, (2) those that arrive from the environment and need nor bear any relationship to the processor content, (3) those that were activated by previous cues and whose activeness may still be continuing.

Previously-activated images appear to have very little preference over the others. These images would manifest themselves as intrusions into a thought train as the Schwartz and Rouse experiments, described in Chapter III indicated. The occasional existence in a thought train of an image not related to the previous one is accountable by this manifestation. The more interesting situation is the competition between externally originated images and those activated by a cue derived from the image currently in the processor.

Which of the two types is preferred is in part a function of how long the thought train has been going on. If the thought train has just begun there is a strong tendency to choose the next image from among the cue-evoked associates. This is to be expected if, as will be discussed in the next chapter, a major goal of thought train activity is constructing and revising models of the environment, of the self, and of the interface. Then, it makes sense that

we prefer to take an image from the environment, construct a chain of images from memory, in the meantime noting various relationships. If the chain gets long, we emphasize environmental images since the environment might have changed meanwhile. Another variable affecting the selection of one type of image over the other is the nature of the environmental image. Earlier I had identified two factors that affect the priority level to be associated with an externally originated image: (1) the predictability of the outcome represented by it, (2) the expected pay-off due to non-predicted outcomes. In support of this claim, I described the habituation experiments where, for example, a dog is presented with a series of monotonous clicks. Initially the dog pays attention indicating that the images are being consciously processed. After a short while the dog loses interest. This does not mean, however, that it has stopped hearing. Vary the intensity of the click and the dog is once again with it. In order to notice the change in intensity (a relative matter) the dog must have been hearing the click.

That the pay-off is important is indicated by the following: consider two identical iceboxes equipped with thermometers mounted on the outside. Both iceboxes maintain a temperature of 32^{o}F. and both of them once in a while fluctuate by as much as 4^{o}F. One icebox houses a stable chemical the other an unstable chemical which may explode if the temperature varies by 3^{o}F. or more. Although predictabi-

lity of temperature readings is the same for both, the pay-off is associated with non-predicted outcome. Chances are our eyes would be glued to the thermometer on the ice-box with the unstable chemical in it.

Clearly, the nature of the internally generated images plays a role in the selection process. If, for instance, a series of highly exciting thoughts emerge, the person may cut himself off from the environment for a considerable amount of time.

I will summarize, therefore, the selection of image type as follows:

Let

P_e = probability that an external image will be selected

E = degree of predictability of the event represented by the external image

P.O. = pay off or loss due to unexpected outcomes

$P.L._e$ = priority level of the external image

$P.L._i$ = priority level of image chosen from among the cue activated images in the memory

L = length of the thought train up to decision point

X = as yet unidentified factors that affect $P.L._i$

Then

$$P.L._e = f\ (\ |P.O.|\ ,\ 1/E\ )$$

$$P.L._i = f\ (\ 1/L,\ X)$$

And

$$P_e = f\ (P.L._e - P.L._i)$$

where P_e is an increasing function of $(P.L._e - P.L._i)$.

In as much as my primary interest is the thought train itself, the more pertinent inquiry should be into "X". In other words, how is one image selected over many others activated by the cue.

A major source of influence should be sought in the goal currently active.* However, this cannot be the entire source; otherwise thought train would be reduced to directed thinking. Random selection is another source. As was argued at length in Chapter III goals simply influence, not determine the thought train flow. Random selection here and there makes thought train more potent sources of hypotheses, evidences, problems, examples, etc. So it is very likely that, in part, image selection is a random process, that is after, for example, activated images are separated into desirable and undesirable, at random one of the desirable ones is selected. Although often only one image appears to be chosen it is possible that several are chosen and merged. It is hard to rule this out or verify it experimentally. However, if the mind can merge images, and it can do that, it would be efficient at times to combine several images and take the composite image into the processor.

Yet another source of influence should be sought in the nature of feelings generated by the images. The pleasant

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*Goals will be discussed in the next chapter. Assertedly thought train process serves certain functions (goals) some of which are hypotheses generation, evidence generation and problem identification. At any time at most one goal is "active" and exerts some influence on the thought train process by influencing the cue selection as well as the image selection process.

images should be preferred to the unpleasant ones. This is one of the important premises of psychoanalytic theory. The reader may recall his distinct displeasure when a thought train unearths thoughts with undesirable feeling contents.

Sometimes the activated images include a subset in which the members are highly associated with each other e.g. recollections of a movie recently seen. In such cases it appears that a whole sequence or some part of it is fed into the processor one by one.

Characteristics other than the feeling content of images should be expected to influence the selection process. One such characteristic is the recency of the image. In view of the memory organization goal, the more recent images should be more preferable. Another characteristic is the frequency with which an image appears among the activated ones. Either the most frequent or the least frequent one may be preferable.

In summary some of the possible determinants of selecting an image from among the cue-activated associates are:

1. the active goal; this imposes some but not all of the screening criteria.
2. characteristics of the images
    a. feeling content; possibly the very unpleasant ones are rejected.
    b. recency; the more recent ones may be preferred.

c. relative frequency among the activated images.

d. sense of the image--declarative, imperative, or interrogative. Perhaps declarative is preferred.

3. existence of highly associated sequences; consecutive images would be selected from the sequence.

4. random selection; an image is selected at random either from among the activated ones or from among the ones that pass the screenings. It is possible that once in a while an image among those that are rejected by the screenings is selected. This would allow the evaluation of the various screens and lead to their revisions.

CHAPTER VI

POSSIBLE FUNCTIONS OR GOALS SERVED BY THE THOUGHT TRAIN PROCESS

An activity that occupies a significant amount of our waking hours would be expected to serve some useful functions (goals). As was also stated by Piaget [5], introspection reveals _results_ but not mechanisms responsible for the results. That is why in Chapter III a series of introspective observations (_results_) were interpreted to infer the underlying mechanism. Here I have followed the same procedure, too, and have isolated nine _functions_ which group into three _goals_.

Delayed Response: Insight Formation

Observation: In analyzing my thought trains, I encountered ones in which previously posed problems were suddenly solved. Careful introspective observation of such "sudden insight" or "sudden flash" demonstrated that the solution was associatively related to the _preceding_ image or thought preceding the insight.

I also encountered thought trains where an old problem was associatively retrieved and no solution was obtained. The thought train simply moved on to another thought.

Implications: I therefore would like to propose delayed response to problems as a function served by the thought process and offer the following process as a way of achieving delayed response: if the image selection process encounters, among cue-activated images, an unanswered question with sufficient priority level, then the question as well as the processing done on it until then is brought to consciousness.

The thought train now becomes semi-directed. The processing steps are reviewed; each step being an image, it is capable of sending a cue to the memory and activating the related images. If new data on the problem has entered memory or if new inferences have been made, very probably one step or another will retrieve them.

If the new data or images fit into a critical step, a solution will be forthcoming rapidly. If no solution is readily attained, the question along with the reprocessing passes into the short term memory and then into the long term memory. In this round more processing was done; next time the question is recalled, its answer will be even closer.

Observation: Sometimes what is retrieved is not a question but an instruction. It is processed and if appropriate, action is initiated. The reader must have experienced remembering some of the things he had to do associatively.

Implication: The same process suggested for question retrieval is appropriate for instruction retrieval.

Example Generation

Observation: Sometimes when one image in a thought train pertains to a newly encountered statement, the next thought is an example (or an instance of it) often pertaining to self or very familiar people.

Implications: Another function of thought train process may be generating examples. Examples are very important for comprehension. A novel statement followed by an example often is "understood". A novel statement for which no examples are provided, at least for a while, draws a blank. "Give an example" is a commonly encountered request.

Perhaps one reason for the importance of examples is that they relate the novel idea to relations or events that are long established and have rich deep structures. Therefore, through an example the new statement becomes associated with extensive interconnections of thoughts and hence gains meaning. This is quite in accordance with recent studies which indicate a strong correlation between meaning of something and the number of associations it evokes.

Another reason for the importance of examples may be that they form templates for predicate transfer. A predicate is a relationship pertaining to a subject (noun). Presumably an example contains some of the necessary or even sufficient conditions for a subject to have the predicate or for the

predicate to belong to the subject. So when it is desired to impart a predicate to a new subject, retrieval or presentation of an example containing the predicate could immediately reveal some of the sufficient and/or necessary conditions which may then be applied to the subject.

Since a statement is a subject plus a predicate there are two ways of generating examples: (1) finding an image that contains the predicate and a special case of the subject, (2) finding an image containing the predicate and replacing the subject with a special case of the subject of the novel statement. I hypothesize that both are used in thought trains.

Insight into this can be gained by asking subjects to generate examples and then examining the examples. Such experimentation was not conducted here. It is suggested for future studies of this topic.

Association Formation

Observation: Some thought trains contain frequently recurring sequences. Sometimes, when an image X is followed by a very interesting image Y, next time X or its variant is encountered, Y often ensues.

Implication: Another function of thought train appears to be forming associative chains. Actually the whole thought train is an associative chain. However, the associations of those sequences in this chain that are interesting

(according to current criteria of interestingness) appear to be more permanently stored in memory.

This is not surprising in view of our ready ability to form all sorts of associations. Experiments on paradigms by Bousefield _et al._ show that when a word and a number are associated, subconsciously the associates of the word and the number are also associated. [7]

It is as if thought train is taking primitive images and forming _modules_ that can serve as inputs to a variety of mental activities. Of course forming such modules which in time may grow into whole patterns should _facilitate retrievel, storage and processing_. That this may indeed be the case is illustrated by the following "trick" for bettering retention. Create a paired list as follows: one for gun, two for ten, three for free, four for door etc. Now given a list of words to be memorized e.g. steel, wood, man, dance, form association like "gun is from steel", "tea in wood boxes", "man is born free", "dance through the door", You will very quickly memorize the list i.e. _your storage time will be shorter_; you will easily remember the list--your _retrieval time_ of the list will be less; and also you will _process_ the list much more readily--you will easily locate the third number.

Meaning also has something to do with the number of associations--the more the associations evoked the more meaningful is the word. To an extent, problem solving capability rests on abductive logic (decision structure for

selecting the appropriate rules or subroutines) which in turn depends on associations formed between rules and the stimuli they are appropriate for.

In other words forming associations appears important for a variety of mental phenomena. So it is advantageous to form the associations for newly arrived images yet in the short term memory. Directed thinking cannot handle this task as its "universe" or concern domain is limited. However, the task seems very appropriate for thought train process. The latter, in fact, is really forming all sorts of associations, where "direction" is of limited duration. Hence the assertion here, that one of the functions of non-directed thinking is <u>forming various associations</u> whose importance may not be immediately obvious or known. Notice, for instance, how at night we form all sorts of thought trains with images acquired during the day. Indeed it seems that each time we are not concentrating on a task, a thought train links a recent image with more established ones.

Selective Memory Retention

<u>Observation</u>: Images that appear in a thought train seem to be easily rememberable later on. This is of course a special case of the well known fact that repetition improves retention i.e. retards forgetting.

<u>Implication</u>: The mechanics of forgetting is still ill-understood. One can postulate <u>constant decay</u>. This, however, would not explain selective forgetting. Since repetition of an image is really like re-storing that image

selective repetition would indeed bring about selective forgetting. This would be true even when a constant memory decay applies to all images. These hypotheses are quite in congruence with the von Foerster model of forgetting, discussed in Chapter IV.

I posit that thought train is just the process for selective repetition of images,and as such one of its functions is aiding the retention of more useful images or,equivalently,aiding selective forgetting.

Schwartz and Rouse experiments discussed in Chapter IV established that the cue-activated images are retained even into recognition test. So cue activation is one way thought train helps selective forgetting. The previous section indicated that associations also improve retention. Insofar as thought train increases associations it also selects out the associated images for longer retention.

Chapter IV clearly indicated the existence of short term memory where decay rate is much faster. Very likely many mechanisms are at work for consolidating short term traces into long term memory. Thought train appears to be another mechanism of this kind. The preponderance of recently acquired images in thought trains attests to this. Whereas other mechanisms achieve consolidation according to established algorithms, thought train may be bringing more

flexibility, experimentation and a degree of randomness. The end result may be the revision of automated processes of selectively fixing short term traces to long term engrams.

Memory Organization: The Basic Function

The functions described so far are subsumed by one function: memory organization. In other words, example formation, delayed response, increased connectivity, and aiding selective memory retention all underly this major function.

Below, I shall discuss counter-example formation, inductive inference and problem generation as subfunctions of yet another possibly basic function of thought train process: hypothesis generation.

Counter-Example Formation:
Evidence Generation

Observation: In some thought trains the image of a novel statement is followed by an instance where the statement does not hold i.e. a counter-example.

Implications: Verification of statements acquired from the environment is an important mental task. One way of doing this is to isolate situations where the statement does not hold e.g. the opposite of the postulated predicate holds for the subject or a special case of the subject.

Through mechanisms described under example formation thought train process should be capable of and in fact does generate the counter examples. I, therefore, posit that another function of the thought train process is exception

or counter-example generation.

Evidence Generation

Example generation was presented as serving memory organization. It also serves to collect evidence for a statement. Exception generation serves to collect counter evidence. In essence, both of them serve to test the truth of a statement at hand. In as much as a statement is really a hypothesis about its subject, this is equivalent to hypothesis testing.

That this is indeed a function served by thought train process can be seen by examining one's thought trains especially at night. They contain numerous externally and internally generated hypotheses followed by examples which verify or weaken them.

Inductive Inference

Observation: Some thought trains result in inductive inferences. While associatively passing from one image to another a relationship basic to them is discovered. Since the relationship is obtained from specific instances the relationship can legitimately be called inductive inference.

Implications: In my estimation, inductive inference of predicates is a very important function of the thought train process. Inference of predicates is a very important function of the thought train process. Let me amplify this proposition by outlining a method. When an image is in the

processor its properties are matched (logically intersected) with those of the images that were in the processor immediately before but now are in the follower (short term memory). Let X denote the resultant common properties. X contains at least one element, the cue component. If members of X are many, then the same cue is used to retrieve the next image. Now X and the new image are intersected. If the resultant X' is still large, the procedure continues a few more times. At the end it is induced that the cue component and other members of X' are related whereupon other operations or rules might be called to determine the nature of the relationship. Evidence generation may then be used to substantiate the hypotheses about the cue component and other components in X'.

The inference thus generated may be quite incorrect. However, people do make wrong inductions. In fact, for some people it is a habit to jump to conclusions on the basis of very weak relationships. One time or another we all experience suddenly inferring a "truth" or relationship only to find it to be wrong.

Undoubtedly many other rules are used to generate hypotheses. However, the method described as it operates within the framework of non-directed thinking can be a potent source of hypotheses.

Problem Finding

Observation: In some thought trains one image is that of the accomplishment achieved during the day. The

next image is that of what had been aspired for that activity. Third and ensuing images relate to a plan of action based on the comparison of what is achieved with what was aspired.

Implication: This is a case of problem generation in the Pounds sense of problem [22]. He states that a problem can be thought of as being perceived when a difference is noted between the actual results and the desired result. Although this may not be a very general definition it is operational and has intuitive appeal.

The above observation pertains to results of being compared with plans or aspirations . Clearly, when a plan or desired activity is encountered in a thought train, it may cause the retrieval of images indicating what was accomplished of that activity. The reader may remember many instances where he first associatively remembered a goal he had set up and then thought that he just had not achieved it. Often such thought trains are interrupted by such comments as "Ah! I should have done that." The unattained goal is then identified as a problem for the next day.

I therefore, posit that another function of thought train process is problem identification or generation.

Hypothesis Generation and Testing: Another Major Function

A major function, memory organization, subsumed the first three functions. Another major function, hypothesis

generation can be considered as subsuming evidence generation, inductive inference and problem generation. All three processes cast some light on the "appearance of hypothesis in the field of consciousness which remains mysterious even in the simplest case." [5]. Of course once a hypothesis is constructed its significance need not be determined or appreciated. As Leray contends and Piaget corroborates [17] on coming back later to conscious efforts the line of inquiry which we had neglected before appears more important than it seemed before because now it is interpreted within a new context. It seems the thought train process both generates hypotheses in a non-directed manner (i.e. with no goal to generate a particular hypothesis) and also associates these hypotheses again in a non-directed manner with various contexts. Once in a while a hypothesis really makes sense in a context and the results (as Piaget reports and as I have argued) emerges as a sudden discovery.

Consciousness Creation: Another Major Function

The two main functions described so far would suffice to justify the mind's being engaged in thought trains a significant portion of its waking hours. However, I will try to identify yet another function which although relates to the previous two, still has different characteristics to merit a separate name. I will call it consciousness creation.

Definition of Consciousness

I view consciousness as perception of alternatives. For such perception the organism must have a model(s) of the action environment, a model(s) of itself, and also a model(s) how the self and the environment are related i.e. interface models. Consciousness is, then, determining the action alternatives by interrelating the environmental, self and interface models.* An illustration: you are casually walking on the sidewalk without really being conscious of your feet action. Suddenly you slip lightly and walking enters your consciousness. You will notice that at that point we become aware of: (1) the environment in which the feet are operating, (2) how the feet operate, a knowledge presumably gained throughout childhood and (3) alternatives of action i.e. ways of taking ensuing steps so that a slip does not occur again. These alternatives depend on the first two models as well as on how the feet operate in the environment, that is to say interface models. After a few more steps, walking once again disappears from consciousness. The automatic mechanisms take over. This of course, does not mean information about walking is no longer being recorded. On the contrary. We can easily remember our "unconscious" activities. However, information

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*A possible physiological basis for consciousness was attempted in the chapter on memory models.

coming from such activities does not activate alternative generation.

Very likely non-directed thinking plays an essential role in building the self, environmental and interface models. Future studies of the process may reveal the various bases of this role. Here, I will briefly consider the last facet of consciousness: interface model building.

Alteration of Feeling Codings

Observation: It is possible to associate a feeling with each image in a thought train.

When thought train is interrupted, a specific feeling remains hanging in the chest. After the interruption is over, if the thought train is to be continued a retracing is undertaken. When the interrupted image is reached, the feeling in the chest disappears.

Both observations indicate that an image contains feeling codings. The conditioning experiments of course, corroborate these observations.

Implications: It seems to me that a feeling is nothing more than an indicator of how an event or object is represented by an image in memory, relates to the organism. As such, feelings are the essence of interface models. They signal h o w the environment impinges upon the self whereupon the organism is prepared accordingly by (for example) increasing heart beat and dilating the pupil.*

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*It is reported that "pleasant" events cause a dilation of the pupil. (Scientific American, June, 1964).

How is relational representation via feelings achieved? When an event directly affects the organism like a hot stove burning the finger or skiing causing a broken leg representation is relatively simple. However, many of the relations are perceived, projected or predicted. One way to do this is to compare the incoming image with images in the memory, find its analogs and attribute to the new image the same feeling codings. Example: we casually meet a person at a social gathering. We do not see him again that evening. However, later we discover that we harbor strong negative feelings towards him. Close scrutiny reveals that this person resembles a hometown friend we violently hated. Apparently the new image was given the negative emotional coding through a transfer of coding from the analogous image.

The thought trains as they form all sorts of links among images in memory may at the same time be facilitating alterations in feeling codings and hence aiding the formation and revisions of interface models which in turn expand or increase <u>consciousness</u> as they create <u>action alternatives</u>. Hence the name given here to this function: consciousness formation.

Expansion of Models

In discussing the macro model I had mentioned the observation that the thought trains are often triggered by images coming from the environment and that the image

selection process receives two types of images: cue-activated and externally originated. If one of the latter is chosen and sent to conscious processor it becomes the basis of a thought train. This, of course, links it to stored images of all sorts and starts the process of incorporating the <u>event image into the models</u>. One facet of this is feeling coding which has already been discussed.

So thought train can be viewed as incorporating new images into the mental models and also revising those models and in this sense creating more consciousness.

The three major functions attributable to non-directed thinking appear below with associated subfunctions. The classification is not mutually exclusive. As with virtually all mental classification there are overlaps.

1. memory organization
   - delayed response
   - example formation
   - increasing connectivity
   - aiding selective memory reinforcement

2. consciousness creation
   - attaching feeling codings
   - incorporating new images into mental models
   - (facilitating interface models)

3. hypothesis generation
   - counter-example formation
   - inductive inference
   - problem generation

Thought Train Viewed as Background Noise

These functions or goals do not completely structure thought trains but simply influence them. In fact as a thought train is proceeding under the influence of one goal, the results may activate another goal which then gives partial direction to thought train. Even then there appears to be a great deal of randomness; cues and images are chosen at times for no obvious reason. This is the characteristic as well as the source of the usefulness of non-directed thinking. The results of the partially random wanderings in the memory are scrutinized by various heuristics for relevance to the goals. If a goal is activated it is then that the non-directed thinking acquires some direction so as to serve the goal but after a while becomes random again.

From this viewpoint thought train is basically mental noise. Lest it be thought that such an interpretation is equivalent to considering thought train useless and even harmful.The following passage from Fogel is both appropriate and illuminating:

> At the lower levels of structural complexity noise is almost always a degrading factor. It has been shown, however, that at a higher level of logical complexity noise can serve a useful purpose by releasing the domain of those alternatives that are available for consideration. The automata may be said to have 'created' or 'invented' new solutions that may then be recognized as valuable by the ensuing deductive process. By analogy it might follow that the process of human invention is the result of noise internal to brain functioning coupled with careful deductive examination to determine which of the generated products are of immediate utility (that is, which generated products satisfy the constraints of 'necessity').

> The real world is always noisy. The likelihood that this noise will significantly increase the utility of a mute decision is nil. The probability that the result of a noisy moronic decision will happen to fall within the desired range of parametric values is somewhat greater. The search for a valid decision by an optimizing automaton allows even greater opportunity for the useful use of noise, since the feedback provides a deterministic influence toward reaching the desired solution. It appears reasonable to suggest that the greater the logical complexity, the greater the possibility for the use of noise to facilitate reaching a successful decision. [10, p73]

Fogel's arguments especially in the first paragraph strikingly parallel mine. I have, however, gone one step further and have attempted to show what determines necessity and what some of the processes that evaluate noise are. I have also tried to describe the mental noise in terms of mentally experienced events and in particular have provided a description of how it may be generated, namely the thought train model.

CHAPTER VII

PROPOSAL FOR A NEW TYPE OF COMMUNICATION NETWORK WHICH MAY ALSO BE THE BASIS OF INTER-NEURON COMMUNICATION IN THE BRAIN

In as much as the thought train process appears to be instrumental in hypothesis generation and memory organization it is of much pertinence to our efforts to attain intelligence in the machine or in the information system of in particular the firm. Naturally the question arises as to whether current computational facilities will be amenable to the implementation of thought train like processes.

The thought train process squarely rests on extensive associative capabilities or large scale "content-addressability", i.e., specifying data content is sufficient to retrieve files of similar nature. For the process to be of any significance the memory capacity has to be fairly large. Two computational schemes exist which achieve content-addressability: von Neumann type machines (today's commercial digital computer) equipped with list processing languages and associative computers equipped with <u>parallel</u> search <u>and</u> distributed logic.

Serial-Search Computers With List Processing

The serial-search location-addressed digital computer is commercially the most successful machine. Therefore, it is readily available. It has been used mainly for very specific problems. Even in its applications to artificial intelligence it has been used for specific problems of intelligence--calculus problem solving, reading a very limited number of words, answering a small set of questions, etc.

Although this type of machine internally uses location addresses for data, when it is equipped with list processing, to the user the machine appears content-addressable.

A number of list processing languages exist. The best known perhaps are LISP, IPL, COMIT and SLIP. They all can deal with symbolic as well as numeric information. The basic form of data structure consists of a string, list structure or a tree.* Assignment of cells is dynamic, each new cell being added to the structure by creating a link or pointer from within the structure to the cell. The pointer is the location address of the cell being pointed to. All list processors maintain a free storage list and each provide procedures to return used but unconnected cells to the free storage list.

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*A list is any sequence of elements. A string is a list whose elements are not lists.

Typically as much as one-half or even more of the memory and processing time are devoted to the "housekeeping" functions. As the memory grows in size, maintenance of the memory structure, so that it appears content-addressable, threatens to consume a bulk of the memory, and maintenance procedures become very complex.

A major weakness of list processors is that for associative procedures to be possible the memory must be highly structured. This is because the machine is basically serial and frequent exhaustive searches are just not feasible especially when memory is large.

The non-directed thinking process or perhaps all mental processes depend on the ability to perform exhaustive searches. Although commercially not popular, a specie of computers exists which accommodates very frequent exhaustive search: the distributed-logic, parallel-search machine or as it is sometimes called in the literature <u>associative processing computer</u> (APC)

<u>Associative Processing Computers</u>

In associative processing computers often the memory is cellular, all units or "cells" being identical to each other. In the simpler versions the memory is organized as a matrix. Each <u>row</u> is a "word." A register, in which a search word is placed, has pulse lines running along the "columns" of the matrix. That is the first bit position of

the register can send a pulse to the first bits of <u>all</u> the words. When a search word is placed in the register, a pulse representing one of its bits is sent to all the corresponding bits in memory. Those that match remain silent. Those that do not match send pulses along the word line i.e. along the row. The pulses sent along a row arrive in a <u>sense amplifier</u>. All bits of the search word are relayed to memory in this fashion. The sense amplifiers that have received no pulses signal the location of the matching words. An example should make the process clearer.

Assume the search word is 110. The hypothetical associative memory has <u>two</u> word locations. The words stored there are 110 and 010 as depicted in Figure 3 which also has the search word 110 in the <u>compare register</u>.

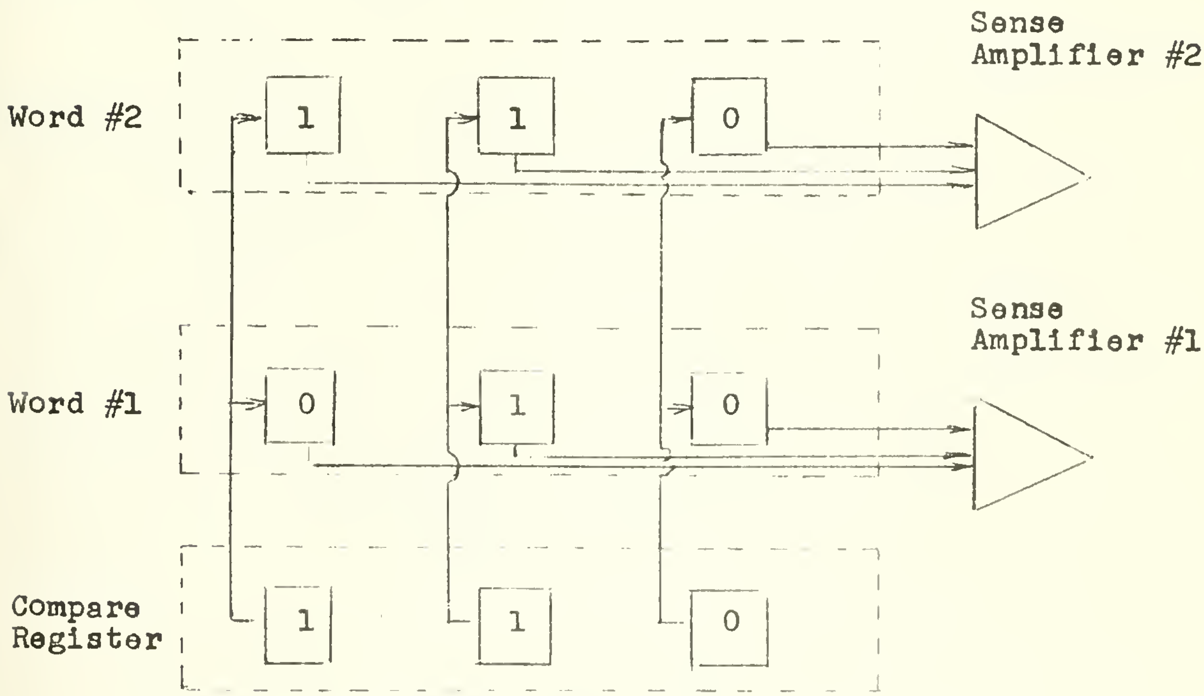


Figure 3.--A Simple Associative Memory

A signal corresponding to "1" is sent along the first bit line. Word #1 sends a pulse to sense amplifier #1. Next a pulse representing "1" is sent along the second bit line. This will cause no pulses along word lines. Finally "0" is sent along the third line. Again no pulses arrive into sense amplifiers. Since sense amplifier #2 received no pulses, word #2 is a matching word.

Either the entire search word or only a portion of it may be subjected to parallel search. When only a portion of the word is used the rest essentially is "masked." Memories permitting one to use an arbitrary portion of the search word are sometimes called fully associative. If the searched portion of a word contains a descriptor of the word, fully associative memories then would permit retrieval on the basis of <u>limited</u> description.

The word lines are equipped also with write amplifiers. Writing at a particular bit location is accomplished by passing a current through the intersecting bit and word lines. By energizing all the word drivers and one bit driver, one bit of each word of a set of words can be written into or "tagged." A schematic representation of the associative memory with both sense and write amplifiers appears in Figure 4. The intersections represent binary storage elements.

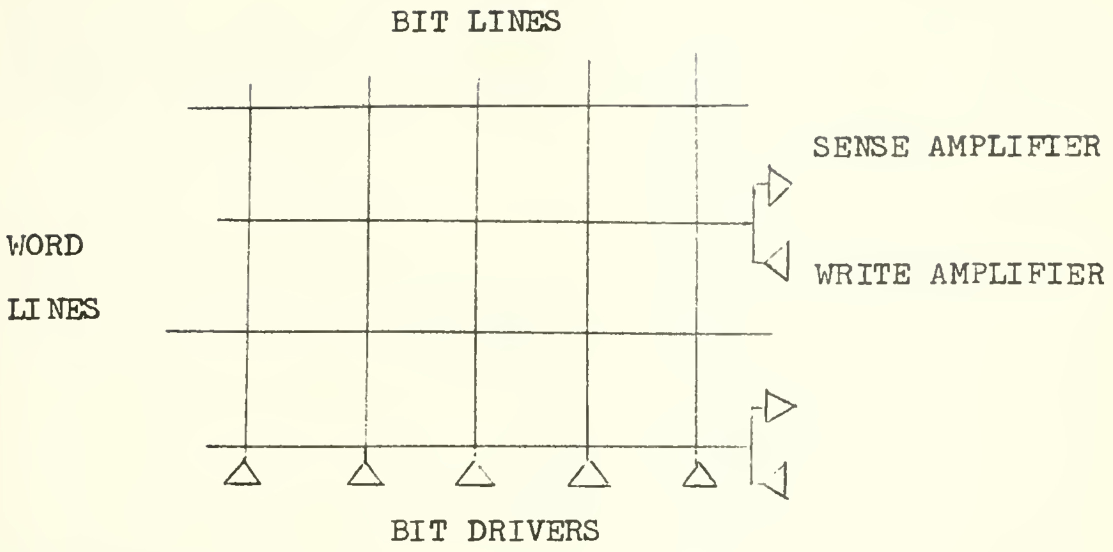


Figure 4.--The General Associative Memory

Associative Memories With Distributed Logic

In more sophisticated realizations of the associative memory each cell has logic capabilities which allow it to perform more than the "match" operation of the simple associative memories. These distributed-logic versions are the ones that can be described as associative processing computers.

C. Y. Lee has descrived a fully associative, distributed-logic memory with intercommunication among its cells [16] . Bistable elements constitute a cell.* Elements are of two kinds: cell state elements, symbol elements. There is only one state element. This element indicates whether

*The Lee machine will be described here because it contrasts so much with the von Neumann serial machine and also because it contains some aspects of the memory model described in Chapter IV.

the cell is in an "active" or in a "quiescent" state. Figure 5 depicts the overall structure of the cell memory.

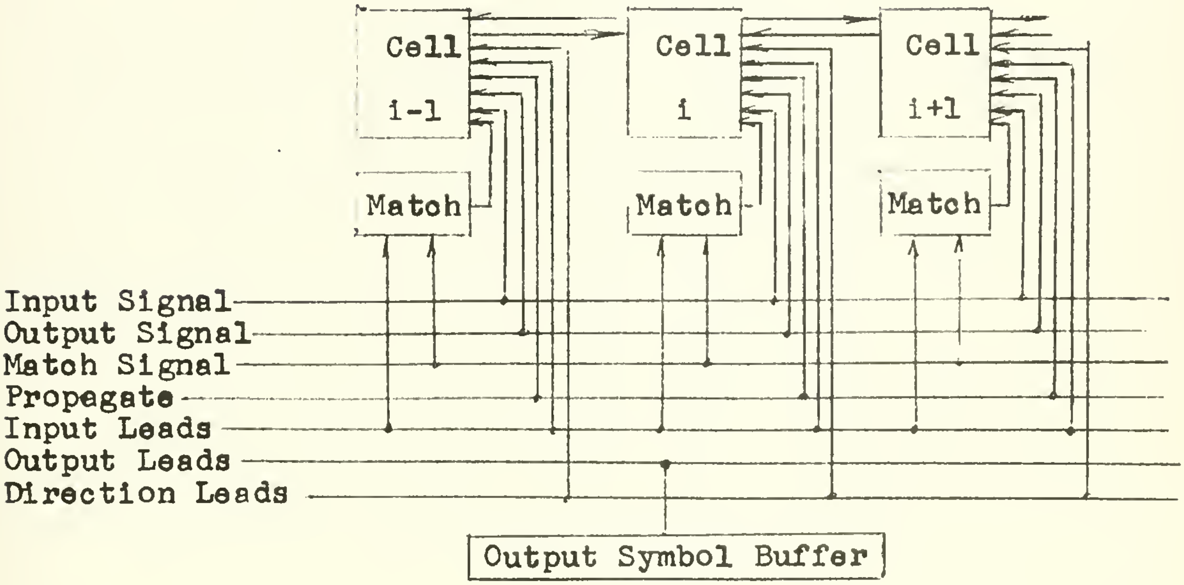


Figure 5:—An Associative Computer

Four types of control leads control a cell and these are the input signal lead, the match signal lead, the propagation lead, and the output signal lead. During the input process the input signal lead remains active and the input symbol itself is carried on input leads. If a cell is in the "active state" during the input process, the input symbol is stored in it. Similarly, if a cell is active during the output process, a pulse on the output signal lead causes that cell to read out its contents to the set of output leads.

Match signal lead controls simultaneous matching of the contents of each of the cells with some fixed contents. Propagation of activity in a cell memory is controlled by the propagation leads. By pulsing these leads the activity of a cell is passed on to one of its neighbors (i.e. neighboring cells are made active), the direction of propagation being controlled by two separate direction leads. This configuration allows one to choose domains from the memory, depending on the problem or the solution step of a problem, and operate on those domains.

The intercommunication feature is also achieved on The Solomon computer, a parallel network machine [28]. Each "cell" or "processing element" possesses 4096 bits of core storage and can perform arithmetic and logic. Each processing element communicates with its adjacent neighbors above, below, to the right, and to the left. A central control unit coordinates the activities of the processing units.

Clearly associative computers have gone through a development stage; the technology for building them has been developed as well as the software technology for implementation on them.

Associative Computers: Main Characteristics

The associative computer is based on parallel search. Therefore, its basic feature is its ability to exhaustively examine the contents of its memory. It has other characteristics worth mentioning.

A consequence of the parallel search feature is that search time is independent of the memory size. This is an enormous advantage when large size data bases are to be actively manipulated, as in the thought train process. Also associative retrieval does not require complex structuring of the data base--another big advantage.

In the associative computer one cell and its logic is identical to any other cell and its control logic. If a cell fails, the system remains insensitive to this local malfunction.

Just as the system can tolerate local malfunctions it can "tolerate" addition of memory units either blank or containing data. In fact blocks of memory can simply be plugged in.

In the intercommunicating versions each cell determines whether it wants to be included in a search procedure. This allows for dynamic memory organization and distributes logic throughout memory.

To sum up then, associative computers achieve: (1) very easy exhaustive search, (2) independence of search time from memory size, (3) insensitivity to local malfunctions, (4) ability to incorporate new blocks of data, (5) distribution of logic and (6) dynamic partitioning of the memory into active and passive domains.

It would appear, then, that associative computers would be the ideal machines for attaining non-directed thinking. However, there is a drawback to be discussed below.

Serial vs Parallel Machine For Non-Directed Processing

While associative computers exhibit some very desirable characteristics from the viewpoint of non-directed processing they have one important short-coming: directed intercommunication is singularly difficult especially when logic possessing modules reach millions, provided no addresses are used. On the other hand the von Neumann machine does facilitate directed search but is singularly lacking in its ability for exhaustive search.

A short-coming of both types of machines is that they are central. Data flows into a central location and coordination is centrally done. Although logic is distributed in the associative computer, control is not.

The memory model supporting the thought train process emerged as one having exhaustive as well as directed search

capabilities and also distribution of control. Any neuron was viewed as being able to form networks with other units and this network was claimed to be the memory as well as the processing unit for the task at hand. However, in the brain, how can parallel search, directed search, network formation, distribution of control and processing all be possible and feasible at the same time without the use of location identifiers? The answer is far from simple since we know that neurons are not perfectly interconnected i.e. one neuron is not directly connected to all other neurons but only to some of its neighbors. Since presumably between two members of a network there may be thousands if not millions of neurons serving as transmitters, how is directionality achieved?

A Proposal For A Network Scheme That Achieves Exhaustive and Directed Search Without Location Identifiers

An analogy to the problem of exhaustive and directed search can bring the issues into sharper focus. Consider the following. There are 1000 people. Each person can initiate a problem. It is desired that the initiator be able to canvas all others on his problem and form a consortium only with those having information relevant to the problem. Once the consortium is formed it is desired that messages flow within the network. People are to remain stationary.

* Since this paper was written, I have greatly expanded on the network proposal described here and have extended it very successfully to pattern recognition. The findings will be reported in two forthcoming papers by the author. Titles are indicated in [25] and [25a].

Perhaps a better analog is this. A large concern (e.g. the Government) has 1000 computers scattered throughout the country. When a computer faces a problem it wants to find out if any of the other computers can be of help and if so communicate directly with those computers.

Two methods for solving such a problem suggest themselves. One is to connect each computer with all the others. This would require $\frac{1000 \times 999}{2}$ or about 500,000 lines. Each computer would require a switching box to handle 999 calls that can come in and 999 calls that can go out. To say the least this is expensive and cumbersome. And, of course, when we go to 10^{10} computers (the approximate number of neurons in the brain) we would need about 5×10^{19} lines or <u>five billion</u> lines per computer. Clearly this is <u>not</u> the way the brain has solved its problem.

The other method is to connect each computer to its neighbors and operate on the basis of parallel search for all communications. Besides congesting channels rapidly this method would not solve the directed communication problem.

What has to be shown is that a unit (neuron, person, computer, etc) in a partially interconnected scheme can hook up with another unit, whose location and identity are totally unknown, solely on the basis of messages sent and received.

Even if the identity is known it is no easy task to form a path. Assume, for example, that you are in a huge

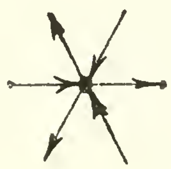
stadium and you want to communicate with your friend John Doe. He is in the stadium but his whereabouts is not known. Asking people sitting next to you to pass your message to John Doe will not help because they do not know who he is or where he is. The only way out is to ask people around you to pass the message to all the people around them. This is tantamount to parallel search. Eventually your message will get to John. He will have received the same message from several people around him who in turn received it from several people and so on. Now how can John Doe return the message to you without resorting to parallel search?

I shall solve this problem for situations where the source and replier do not need names. It will be based on a special network. Undoubtedly a much more general and sophisticated network is utilized in the brain. However, for my purposes demonstrating the possibility of a scheme which produces a simple solution is sufficient.

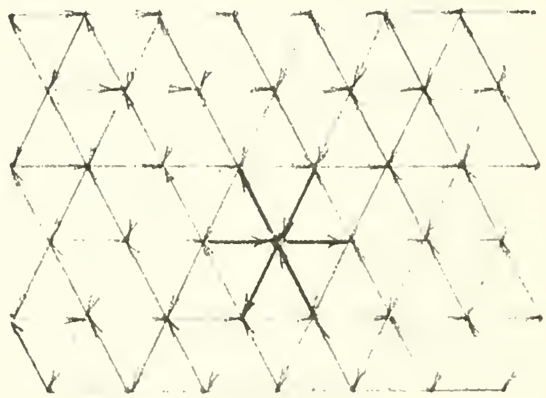
The Development of A Solution

A basic characteristic of the neuron motivated the development--that its channels are one-way only. A dendrite conducts only towards the neuron, and the axon away from the neuron. It is estimated that a neuron may have as many as 1000 points of contact with others i.e. 1000 possible channels. For obvious reasons I have used much fewer than that--<u>three</u> incoming channels and <u>three</u> outgoing channels. Each channel supports transmission in <u>one</u> direction only.

Many patterns of interconnection are possible. After some experimentation the hexagonal pattern shown in Figure 6 emerged as the simplest one. It was also the only one I could find that made all the elements identical.



The Basic Pattern



The Basic Pattern Repeated

Figure 6:--Hexagonal Interconnection of Units With Three Incoming Three Outgoing Channels

All channels are of the same length and transmission takes the same on all of them. It appears to me that networks with different transmission times would afford even greater flexibility but at the expense of added complexity.

The following rules constitute the algorithm which when applied to a network constructed as in Figure 6 will achieve directed intercommunication <u>without</u> the coordination of a central monitor. It is assumed that each unit has logic and memory.

1. The <u>initiating</u> unit (<u>the source</u>) emits on all three channels. It labels its message <u>general</u>.

2. A unit receiving a general message transmits this on all channels.
3. If the same general message again arrives a little later, it is ignored.
4. It can be seen by inspection that all units receive the general message simultaneously from two non-adjacent channels excepting three units surrounding the source which receive it on one channel. A unit is expected to remember which of its three incoming channels brought the message.
5. When a unit wants to respond to the message, it labels its response as special and transmits it on only two channels one of which must be between the two incoming channels that had delivered the general message.
6. A unit which receives a special message transmits it only on the channel that is between the two incoming channels that had brought in the general message.
7. If only one channel brought the general message in then the special message is emitted on the outgoing channel that is adjacent to that incoming channel.

These steps will assure that the special messages from all of the interested units arrive to the source. Suppose now that after receiving the special message from an interested

unit, the source wants to send a message to the interested unit. The following steps would accomplish that.

8. The source labels its new message <u>directed</u> and includes a portion of the initial general message. The <u>directed</u> message is emitted on all three channels by the source.

9. When a unit receives the directed message if it had received the special message, then it emits the directed message on two outgoing channels adjacent to the incoming channel that had brought the special message in.

It was to achieve directed communication <u>from the source to the responding unit</u> that in step 5 it was required that the responding unit emit its response on <u>two</u> channels. If the responding unit does not wish to receive any directed messages from the source, it can preserve its anonymity by transmitting the special message only on the outgoing channel that is between the two incoming channels that brought in the general message.

The rules that an intermediary unit needs to know are:

1. If a <u>general</u> message arrives emit it on all channels.

2. If the <u>same</u> general message arrives a second time ignore it.

3. When a special message arrives:

a. if the general message arrived simultaneously

on two channels emit the special channel on the channel between the two incoming channels.

b. if the general message arrived on one channel, emit the special message on a channel adjacent to that incoming channel.

4. When a directed message arrives, transmit it on all channels only if a "special message" had been received earlier.

An example has been worked out in Figure 7 and should make the steps in the algorithm clearer.

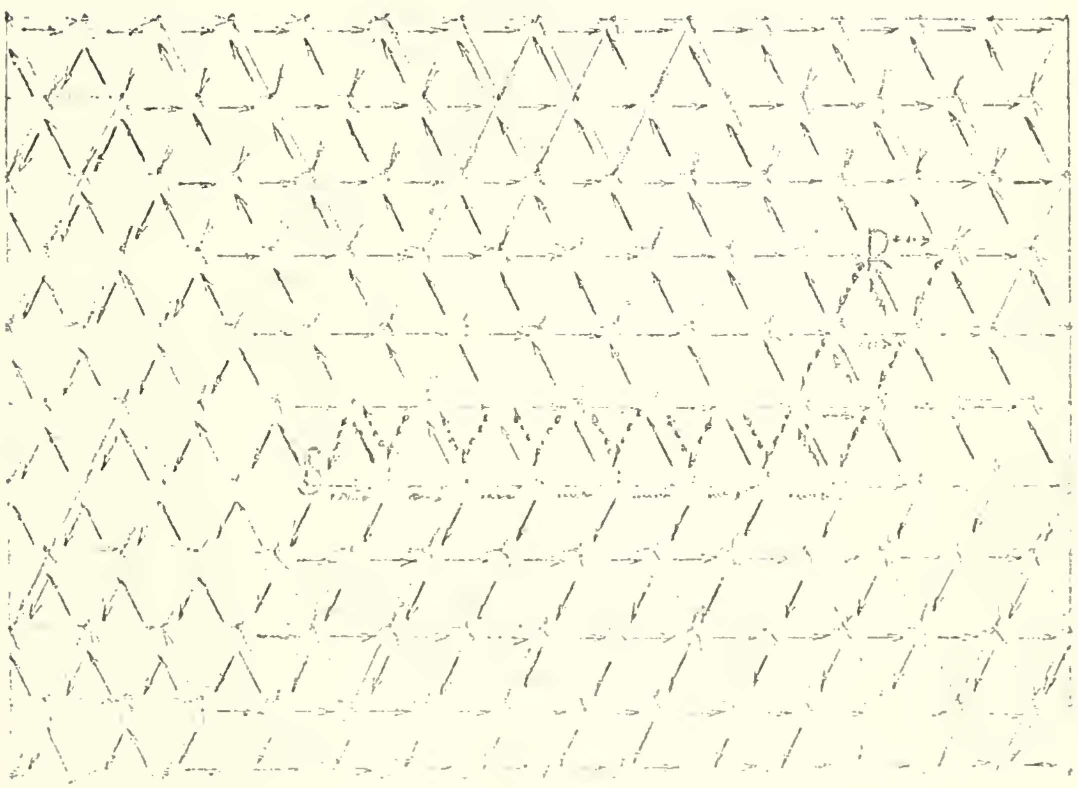


FIGURE 7

: GENERAL MESSAGE

CHAPTER VIII

IMPLICATIONS FOR MANAGEMENT INFORMATION SYSTEMS

The Firm: Its Nature

The firm is an organization much like the biological organisms in that it, too, is adaptive, self-organizing, goal-directed and operates with limited resources in a probabilistic environment. Its basic concerns, too, are survival, continuity, and assurance of continuity or entrenchment. These produce the operational goals within the environment of the firm. Its information system, much like the nervous system, represents and measures objects, events and relationships of interest, processes recording and communicates the measurements and the representations. The components of the management information system are both machines and human beings.

Interestingly, the ensemble of human components can be viewed as very similar to the memory model. Each unit i.e. person has plenty of logic and memory. Intercommunication and interaction goes on all the time. Parallel search of sorts is possible. In an extreme case, one shout across the room reaches everybody; or a person notifies the department heads who in turn notify their subordinates. Through intercommunication each person develops a model of what the other members of the firm know. Each person also has the

potential to do what other people are doing. What brings about differentiation is the difference in information and processing routines acquired and developed. An appropriate network of people is formed for each task the firm encounters. In the larger divisionalized firm, which would correspond to higher level organisms, control locus is ill-defined. The central office does exert some influence on all parts but it in turn is greatly influenced by subordinate divisions. The extent of the influence varies in accordance with the state of the firm vis a vis its environment. So, in a sense, the larger firm is a distributed logic, distributed control entity with intercommunication and interaction among its human components and with dynamic and specialized network formation.

The Firm: Activity Goals

The firm can be viewed as embodiment of a conversion process: inputs flow into it; they are converted into an array of products; the products are then exchanged for an array of inputs. The conversion process is undertaken to satisfy the set of basic concerns (existence, continuity of existence, and the assurance of continuity) and in particular to achieve the objectives that the basic concerns reduce to, in the operational environment of the firm.

In as much as the conversion is a process that is, it is on-going and extends into the future, the objectives must be translated to plans that also extend into the future.

Therefore, planning can be viewed as a primary activity of the management. It generates the expected behaviors or the operational standards and the comparison of the standards with the actuals forms the basis of the control process. Control, then, is a secondary activity.

The planning process squarely rests on predicting future events whereupon the management tries to alter the predicted events in ways most favorable to the organizational objectives. Prediction, in turn, depends on hypotheses of all kinds about temporal as well as spatial cause and effect relationships. Great condensation and systematization of the conglemerate of hypotheses which range from beliefs and hunches to carefully observed relations ensues when the hypotheses are combined into models of the environment. To carry on the task of generation of hypotheses and their embodiments in model, the firm has to constantly organize its memory files, change existing measurement, processing and recordation rules.

Prediction is only one facet of planning. What is predicted needs to be altered to realize achievement of objectives. Ability to modify the environment requires two more sets of hypotheses: one set about how the firm operates and another set on how the firm and the environment are coupled. The embodiments of these two sets of hypotheses would be self models and interface models.

So far <u>three goals</u> for the primary activity have emerged. These activity goals are: (1) <u>generation</u> of hypothesis, (2) <u>organization</u> of files and records (memory organization), and (3) <u>synthesis</u> of hypotheses into environment, self, and interface models.

The Firm: Non-Directed Processes In It

The question arises as to whether the firm, too, resorts to non-directed processes to aid it in the activity goals and in particular in generating hypotheses. I think it does. The informal non-task directed chats, coffee sessions, gossip sessions, gripe sessions can be viewed as the background noise which in reality imparts organization to the firm. Few people will deny that many useful ideas, inductions, perceptions of new problems have come out of these sessions.

The Motivation For This Study: The Problem Of Designing Management Information Systems

If the firm already structurally resembles the memory model of Chapter IV, if its basic activity goals parallel those of the thought train process as described in Chapter VI and if the firm does have non-directed processing, what relevance can the present study be to the firm?

It is relevant because it has helped to describe the firm in what I believe to be <u>new</u> terms. More importantly, though, the ideas developed so far are pertinent to our

efforts towards designing and implementing computational machines.

The industrial age was sparked by the development of production machines which became the extensions of man, the maker. These machines, in particular the heat engines, provided the <u>models</u> for man as a biological machine in turn the physiological models of man helped greatly the development of these production machines.

Our times are witnessing the development of another "era." This as yet unnamed era has been sparked by computational machines which are rapidly becoming the extensions of man the thinker, the innovator, the artist. Already the computing machines and the research they generated have provided us with a wealth of models for the mental processes in man. However, we presently have some understanding of the human mind. Just like the physiological models of man helped further develop the production machines, the psychological models of man can significantly enhance the design of computing machines.* There is a more important reason for going from models of man to machine design. If the computing machines are to be <u>extensions</u> of man, then they must be <u>compatible</u> with man and therefore to an extent they must be designed around man.

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*Such convictions have resulted in the growth of a new discipline--Bionics.

It is exactly to the psychological-models-to-machine-design process that this thesis is relevant.

Computation Machines: Extensions Of The Manager

The modern day firm is confronted with even faster increasing complexity in its operational environment. This complexity can be usefully classified as intensive and extensive. Intensive complexity involves a small data domain but the relationships are very involved and intertwined. Extensive complexity covers a very large data base but relatively simpler relationships (underlying patterns) and events.

In the face of intensive complexity the modern manager has fared well. This is to be expected. As a human being the manager can at one sight perceive a multitude of relationships; with great ease attribute meaning to perceived events by making numerous associations in his mind; perform many types of transformations on data taken in; and generate many hypotheses, generalizations, procedures and decisions.

However, the human being as a decision making unit is balking at extensive complexity in three respects: (1) his input channels have very definite capacities e.g. he cannot understand more than 200-300 spoken words a minute and on the average can not read more than 300-400 words per minute, (2) although his memory is fantastically large the data base with respect to a given problem that he can maintain in his head is quite limited, (3) while he can, with great ease, process, transform and link incoming data and data already in memory, the precision of the operations and of the output is

not impressive at times.

While large input capacities, ability to maintain a large data base with respect to any one problem, and ability to manipulate large data bases with ease are essential for dealing with extensive complexity, only a low level of intelligence is required because the relationships are relatively simple. The computing machine is powerful exactly in those areas where the manager is not. Currently, however, in the man-machine systems the computing machine is a "facility" and not an active part of the firm. The humans define and describe the problem and then the machine is employed. For intensive relationships this is perhaps the better set-up. For extensive complexity, however, the much greater input, retention, processing and precision of the machine can be very usefully capitalized on if the machines were endowed with a low level of intelligence. It can then reduce extensive complexity to intensive whereupon the managers can take over. Only when this is attained will the man-machine hook-up be truly integrated. Only then will the computing machine be an extension of man.

Accordingly, the primary problem of management information systems design can be viewed as imparting intelligence to the machine substructure while maintaining compatability with human substructures. This thesis is particularly pertinent to this problem.

Machine Intelligence

In a very simple sense intelligence is discovering order. It also extends to discovering order among orders.

Two primary requisites for intelligence, therefore, are: (1) the ability to form extensive association and (2) the capability to examine the associations in various contexts through time in order to identify the ones that are indicative of order.

I shall shortly investigate the structural (hardware) implications of the first requisite and the software implications of the second. However, I will first clarify my stand on current trends in artificial intelligence.

Some may feel that conventional methods of organizing computing machines is adequate to achieve intelligence. Merely achieving intelligence will not do; we need to have it in enough quantities. Ashby has also argued for this viewpoint [2] . Having the facility to answer some set of questions about baseball games is quite interesting (cf. BASEBALL program) [11]. This would hardly do for a management information system though. The question answering ability must have a much wider coverage and must be supplemented by other capabilities. However, we should not fall into a very common trap that the "much wider coverage" will entail very straightforward extensions of the ideas that solve the simple problem. Often this just is not so. For example, when a model worked out for two participants is used for "n" participants, a whole new array of problems and associated ideas emerge. Also little may be gained by knowing that "a solution exists such that" (a favorite with the mathematician). The essence of the problem is to develop a

practicably attainable solution.

I feel a similar situation exists with respect to current work on machine intelligence. It is highly micro-problem or case oriented and for its purposes conventional machine and software designs have been satisfactory. Undeniably, startling progress has been made. However, to say that intelligent management information systems, or better yet, integrated man-machine systems can be achieved by extension of ideas that have proven useful for "cases" of intelligence is not justified. Providing for enough machine intelligence should be considered a separate problem necessitating new, bold, and unique design schemes.

Structural Requisites of Information Systems

For extensive associations to be possible memory should be content-addressable i.e. specifying either all or part of the contents of a file should be all that is necessary to retrieve easily and quickly that file as well as other files containing related information. This would require exhaustive as well as directed search of memory files.

Inputs impinge upon the firm from many directions. If the computerized information system is to support the multi-channel firm and interpret the messages intelligently, each input point should be able to initiate associative processing. This would call for distribution of logic and of control so that each source unit can interrogate all others.

Normally not all parts or not all units in a computerized information system bear upon a task on hand. Once the information containing units have been identified it should be possible to form a network consisting of them only so that computational resources are best used and so that the system can be involved in many activities simultaneously. Once a task is over, the members of the network in charge of that task should be available for participation in other tasks.

So far the machine structure for attaining intelligence has emerged as one having content-addressability, exhaustive as well as directed search capability, distributed logic, distributed control, multiple-location initiation of processing, and dynamic network formation.

Procedural Requisites

The structural requirements discussed above will make "enough" intelligence more feasible. Actual realization of intelligence enough to handle extensive complexity would derive from heuristics and algorithms or the procedural framework imposed on the structural framework. The superiority of the computational facility alone is not enough no matter what the degree. Consider, for example, a block of lamps, twenty by twenty.* A lamp is either "on" or "off". If each combination represents a pattern, then there are 2^{400} 10^{180} patterns. Supposing we define a binary property on each pattern e.g.

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*This example was described by Ross Ashby [2] .

a pattern is acceptable or unacceptable. This yields $2^{10^{180}}$ properties. If we observe that $10^{10} - 10^{8} \approx 10^{10}$ we realize how large this number is. For more dramatization let us <u>divide</u> this number by the number of atoms in the visible universe which is 2^{220}. We get $2^{10^{180}} / 2^{220} \approx 2^{10^{180}}$. The number is not even touched. So even if each atom represented one property, the entire visible universe would not suffice to record all the properties definable on a simple twenty by twenty block of lamps.

The example well illustrates that the complexity of our environment is insurmountabl by brute force no matter how large our computational ability gets. We need to endow the system with algorithms and heuristics that reduce the complexity of the environment by many orders of magnitude by <u>discovering order</u>.

We have completed some sort of a circle. We started with the problem of discovering order which we claimed to be the essence of intelligence. Now we have come back to it. So let us break out of the circle and examine the procedural requirements.

Discovering order must start with <u>generation of hypotheses</u> about underlying relationships e.g. $y = f(x)$, $y \rightarrow x$, $y \supset x$. The hypotheses must then be <u>tested</u> both against internally stored data and against fresh observations as they are made. Results of testing may generate new hypotheses. Finally, the validated hypotheses must be <u>evaluated</u> as to

their predictive power.

When hypotheses have been validated and evaluated they become "data" and become subject to further ordering. Thus, the process of discovering order extends to finding order among hypotheses. This second level ordering can be described as modeling. In other words, a model is the embodiment of interrelating a conglomerate of hypotheses.

The machine substructure of the information system must therefore be equipped with procedures that accomplish (1) generation of hypotheses and their validation using internal data as well as incoming data, (2) separation of hypotheses through time according to predictive or explanatory power (organization of our knowledge) and (3) ordering of hypotheses--that is synthesizing hypotheses into models.

Compatability

If the computing machine is to be an extension of man, it must transmit information on the order it has discovered in the extensive complexity, to people who can use this information for the achievement of organizational objectives. The communication procedure must be compatible with man's reception procedures. Also communication must be directed to people to whom the relationships that have been identified are relevant.

Again for the intelligence-possessing computing machine to be an extension of man, it must complement, not duplicate,

man's efforts. This is another facet of compatability in the man-machine system.

Both for channeling generated hypotheses to appropriate people and for complementing peoples' activities the machine substructure must know some characteristics of the people it serves with and for, in particular, what each person does and what he wants. That is, <u>profiles</u> of these people must be in the memory bank of the machine. The profiles can of course be static and supplied to the machine and modified entirely from outside. However, the profiles probably are often interrelated and their ensemble represents extensive complexity. The machine being endowed with low level of intelligence could modify, update, and simplify by interrelating the set of profiles if these were placed in its active memory and hence were subject to associative processing. This would be tantamount to machine's having models of an important segment of its operating environment and manipulating them. The models would then facilitate man-machine communication by allowing the machine to appropriately disseminate its hypotheses and also by providing the machine contexts within which to interpret messages flowing in from the environment.

Ultimately it is the decision maker who determines the worth of machine-generated hypotheses. If, however, he were to evaluate the usefulness of every hypothesis generated, he might not have time for anything else. The way out is to pass some of the values on to the machine so that it can perform an initial filtering. Also this would allow the

machine to determine what hypotheses to further develop and what not to develop.

Wiener, having recognized the necessity for transfer of some human values to machines, suggested that this can be done by putting the intelligence possessing i.e. order discovering machine through exercise sessions much like a student [32]. In school the student proposes a variety of lines of inquiry and a multitude of hypotheses and methods. The teachers by "correcting" the exercises where these are expressed, pass on their own value systems to the student.

The Wiener proposal will, I think, have to be implemented when extensive complexity is left to the realm of machine intelligence. However, for it to be possible, the machine must not only have models of its environment but also of itself and of how it fits into the environment (interface models). This is so because in order to develop judgment, the machine must know how what it puts out affects the environment as reflected, for instance, in "corrections" to its output. The interface models would embody the "value system" acquired.

Normally, there is no end to the input that can impinge on machine substructures and no matter how large the capacity not all input can be accommodated. Selectivity is necessary.

The major ingredients of hypotheses are data arriving from the environment. Testing of some hypotheses requires observing portions of the environment and even changing

the environment in specific ways and noting the consequences. Having acquired values with which to judge the importance of hypotheses, the machine would also have acquired values to judge the significance of inputs. Therefore, it would be efficient to leave some input decisions to the machine substructure itself.

In an intelligent, or order discovering system, input is not just recorded; it is related to stored data and processed. At the same time stored data is processed. So, in a sense, externally originated data and internally stored data are competing for being processed. This makes input decisions a function of the internal state of the system. The machine must therefore evolve a value system to guide the allocation of processing capacity.

Even if it is decided that processing will be made available to incoming data, the problems are not over. Not every input type that enters the system can be processed in detail. A few types must be judged _relatively_ more important and accorded the appropriate attention. To make these decisions based on "relativity", though, the available input types must be perceived. In other words, the system must first determine the input types adjudging the importance of each type. Then it could _focus_ on the ones that appear significant. That is, the system must have some kind of a dual-network input set-up in which one network delivers in breadth but shallow coverage and the other in depth and detailed coverage.

It is interesting to note that the current management by exception procedures of the human substructure are based on dual-network input systems. The manager receives, for example, variance reports which provide him with in breadth but shallow coverage of the results of operations. He then activates detailed analyses on some of them. The result is in depth coverage of a few activities.

Proposals For The Design Of Management Information Systems

At this point a recapitulation of the analysis provided of the requirements for machine substructure of the information system is in order.

The basic problem emerged as imparting low level intelligence to machine substructure of the information system while maintaining compatability with the human substructure. The purpose behind this is to delegate problems of extensive complexity for which the machine is better equipped and for which only low level of intelligence is needed. The machine, then, is to reduce extensive complexity to intensive complexity whereupon manager can take over.

Intelligence was viewed as discovering order, which, it was argued, rests heavily on ability to form extensive associations and evaluate the results. This consideration as well as others determined the machine structure for attaining "enough" intelligence as one having content-addressability, exhaustive as well as directed search capability, distributed

logic, distributed control, initiatability of processing from many locations, and dynamic network formation. While discussing procedural requisites, another structural requirement emerged: that the machine be able to sample its operating environment and also collect detailed information on events of interest to the machine.

It was argued that no matter how powerful the machine's computational ability, it is not powerful enough and that procedural requirements have to be fulfilled if the machine as described in the previous paragraph is to discover order on a sufficient scale. It became apparent that we need procedures which achieve (1) generation of hypotheses, (2) organization of memory files, (3) synthesis of models. A model was viewed as the embodiment of order discovered among a conglomerate of hypotheses.

Compatability considerations indicated that the machine store profiles (models) of people it works for and with. Compatability issue further showed that it would be efficient to endow the machine with some "values" possibly by putting it through exercises. For these to be possible, the machine needs procedures for generating environmental, self and interface models.

Efficiency considerations indicated that the machine substructure should have dual network input. It was seen that this would lead to some kind of management by exception, already practiced by the human substructure.

The reader will notice that the structural requirements very closely resemble the accomplishments of the memory model as discussed in Chapter IV and then in Chapter VII. The procedural requirements on the other hand are very similar to the main functions of the thought train process as discussed in Chapter V. This perhaps is not very surprising because after all the human mind is "designed" to be intelligent.

I therefore propose that at this point in time our understanding of the human mind can and should be the basis of designing the structure and the procedures for management information systems that display intelligence. In particular, I propose the implementation of non-directed processes as described in Chapters II, III and VI on a machine subsystem designed as the memory model in Chapter VII.

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APPENDIX: EXERCISES

EXERCISE ONE: PART A

Instructions

1. Look at the first word in the list. Mentally picture what it designates.

2. Do the same for the next word and so on until the list is exhausted.

3. Then return to the first word and write down as clearly as possible what you mentally pictured. Do the same for each of the words that follow.

Trial One

school

governor

field

scholarship

biology

Trial Two

caricature

people

picture

observer

diamond

Trial Three

estimation

interest

fact

emphasis

difficulty

EXERCISE ONE: PART B

Instructions

1. Start with the first word. Recall what you had mentally pictured. Now, picture something else related to it.

2. Record this second image and the relationship between the two images (the cue), i.e., what brought the second image to your mind.

Trial One

caricature

people

picture

observer

diamond

Trial Two

estimation

interest

fact

emphasis

difficulty

EXERCISE TWO

Instructions

1. The following list contains pairs of words. You encountered each word in the first exercise and were asked to mentally picture what is designated. Go through the list and for each word recall the mental picture.

2. Consider the first pair of words. Merge the corresponding mental images, i.e., combine the two mental pictures of the two words.

3. Record in the space provided and in sufficient detail the composite image.

Trial One

school
caricature

people
governor

field
picture

scholarship
observer

biology
diamond

Trial Two

caricature
estimation

people
interest

picture
fact

observer
emphasis

diamond
difficulty

EXERCISE THREE

Instructions

1. Consider the words you encountered in Exercise 1, trials 2 and 3. Recall the mental picture each generated in your mind. These words have been reproduced on page 161.

2. In this experiment you will encounter the same words first with one modifier.

3. Try to visualize the modified word.

4. Record this new mental image in sufficient detail.

5. You will encounter in Trial 2, the same words, this time with two modifiers.

6. Again try to visualize the word in view of both modifiers.

7. Record this new mental image in sufficient detail.

8. The modifiers as well as the words have been chosen at random. The experimenter does not have any set descriptions.

The Word List

caricature

people

picture

observer

diamond

Trial One

rectangular caricature

black people

oblique picture

white observer

orange diamond

Trial Two

violet rectangular caricature

comfortable black people

colorful oblique picture

repulsive white observer

tiny orange diamond

EXERCISE FOUR

Instructions

1. In this exercise you will be given phrases. Each phrase will be numbered.

2. Read the first phrase without reading any of the others. Mentally visualize it as best as you can and record this mental image in sufficient detail.

3. Next, read the second phrase. Visualize and record this image.

4. Continue on with the consecutive phrases in the fashion described above.

Trial One

1. A square topped table

2. A square topped table may appear trapezoidal

3. A square topped table may appear trapezoidal, or diamond-shaped

4. A square topped table may appear trapezoidal, or diamond-shaped, yet the child will learn

5. A square topped table may appear trapezoidal, or diamond-shaped, yet the child will learn that its identity is unchanged.

Trial Two

1. Auto-safety

2. Auto-safety planners

3. Auto-safety planners are considering

4. Auto-safety planners are considering more than a dozen novel features

5. Auto-safety planners are considering more than a dozen novel features that probably will be required equipment

6. Auto-safety planners are considering more than a dozen novel features that probably will be required equipment on cars

Trial Three

1. Scattered Communist attacks

2. Scattered Communist attacks and sporadic fire fights

3. Scattered Communist attacks and sporadic fire fights were reported

4. Scattered Communist attacks and sporadic fire fights were reported in South Vietnam's central highlands

5. Scattered Communist attacks and sporadic fire fights were reported in South Vietnam's central highlands and the northern sector

6. Scattered Communist attacks and sporadic fire fights were reported in South Vietnam's central highlands and the northern sector just below the demilitarized zone

Date Due

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